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National Electric Light Association, New York, June 4-8

Pacific Coast Electrical Association, San Francisco, June 19-22

Society of Industrial Engineers, Cincinnati, April 18-20

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Ground Selector for Ungrounded Three-Phase Distribution Systems

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Review of the Subject.—*Ever since three-phase distribution has been known, a controversy has been going on with respect to the relative merits of grounded and ungrounded neutral. The inability of locating and isolating a ground fault is the chief disadvantage of the ungrounded neutral system, this being the reason why lately the grounded neutral has been given preference.*

The purpose of the so-called ground selector is to provide means to permit the selective clearance of a ground fault in an ungrounded neutral system. The device thus eliminates the mentioned disadvantage and raises the ungrounded neutral system to the same operating standard as the grounded neutral system, retaining at the same time the many other advantages inherent to the ungrounded system.

The paper describes the functioning of the ground selector and compares in detail the two systems. Two ground selector installations on largely different systems are described and the practical operating results are reported and discussed.

The conclusion is reached that the ungrounded neutral system equipped with a ground selector combines the advantages of the ungrounded and grounded neutral systems without being afflicted with their respective disadvantages.

Introduction

The question of the advisability of operating three-phase distribution systems grounded or ungrounded has, within the past ten years, formed one of the liveliest subjects for discussion among transmission engineers. The reason for the greatly diversified opinion on this subject is chiefly due to the fact that either principle has its pronounced advantages and disadvantages.

In the early days of three-phase transmission the ungrounded system was used almost exclusively except where it was developed as a four-wire system.

With the increase in transmission and distribution voltages, insulation troubles started to multiply. Grounds started to develop quite frequently. It was then discovered that the ungrounded system was at an extreme disadvantage, particularly in case of extensive distributing systems, because there was no means available to detect and select the faulty feeder. Moreover the grounded phase produced a 73 per cent voltage rise between ground and the two sound phases. Such dynamic overvoltage, sometimes aggravated by resonance effects from an unstable arc at the point of fault, usually resulted in secondary breakdowns of weak insulation at entirely different parts of the system. Thus a short circuit developed disturbing the whole system and extending the damage unnecessarily to other parts of the system. A ground, left on the system for any appreciable time, was found to also have its weakening effect on the whole metallically interconnected system and would thus prepare for future troubles. It was soon discovered, therefore, that continuing to operate on a ground fault was detrimental.

Improvements were suggested such as Creighton's arc suppressor to render the ungrounded system safer. These improvements however failed chiefly in view of the fact that they aimed at the less vital disadvantage of the ungrounded system, namely the suppression of an arcing ground. They offered no solution, however, for detecting and selecting a faulty feeder.

As a result of this weakness of the ungrounded system the operating engineer's opinion gradually expressed in favor of the grounded system despite many disadvantages in regard to transformer connections. In the grounded system every ground meant a short circuit thus supplying the current necessary to operate relays and assure clearance of the faulty feeders. Thus the grounded system offered a natural solution for the most troublesome feature of the ungrounded system.

Today the stage has been reached where the general opinion is overwhelmingly in favor of the grounded system. Many operating companies, which have operated ungrounded in the past, have changed in recent years to grounded systems by devising various means of grounding.

The writer, being connected with a large distribution system with delta-connected transformers was, some years ago, confronted with the same problem of overcoming the serious conditions created by a ground on the ungrounded system as described above. Circumstances were such that grounding, either by changing to star-connected transformers or by providing an artificial grounding scheme, was not readily possible. He was forced therefore to the development of another scheme which is hereafter called "ground selector."

The purpose of this paper is to give a brief description of this scheme, to point out its advantages substantiated by actual operating records and to show how the ungrounded system equipped with a ground selector retains practically all inherent advantages of the ungrounded system and at the same time assures the same

To be presented at the Spring Convention, Pittsburgh, April 24-26, 1923.

effectiveness of clearing grounded lines as would be the case with the grounded system.

Description of the Ground Selector[1]

A ground, occurring on a non-grounded distribution system, will be felt over the whole system. There is normally no means available to locate the faulty line except by disconnecting alternately individual sections of the system and observing whether the ground disappears. Such cut-and-try method is rather slow and always necessitates the momentary interruption of a larger part of the system than necessary, since many of the sound feeders may first be disconnected until the faulty feeder is located. The ground will cause a 73 per cent increase of voltage on the two sound phases to ground, and if left on for any length of time may cause the breakdown of another weak spot at an entirely different part of the system.

To reduce to a minimum the damaging effect of a ground, it is essential to provide means to have the grounded section cut out selectively and within the shortest possible time.

The ground selector has been developed to accomplish such selective and immediate clearance of a grounded feeder.

The fundamental idea of the ground selector is to produce intentionally a short circuit immediately after a ground develops on the system. This is accomplished by automatically grounding one of the sound phases at the main station bus by means of closing an oil switch, immediately upon the occurrence of a ground. Thus a complete phase-to-phase short circuit is produced and as a result overload current will flow into the faulty line, as if the line were on short circuit. Accordingly the ordinary overload protection will enter into action and disconnect the faulty line. As soon as the faulty feeder has cleared itself, the ground switch will open automatically and thus restore the system to normal condition.

Figure 1 shows schematically the principal features of the device. P 1-P 2-P 3 are single-phase potential transformers with their primary connected in star and with the star point grounded. The secondary of these transformers is connected to overvoltage relays R 1, R 2 and R 3, which latter, two in joint action, close the ground switches. The so-called transfer relays T 1 and T 2 are provided to assure an automatic clearance of the ground switch after the faulty line has cleared, as will be explained later.

Normally the three phases of the system will be balanced to ground, and as a result the potential on the transformer P 1, P 2 and P 3 will be the same and equal 58 per cent of the voltage between wires. A ground on one phase will tend to lower the voltage on the transformer, which corresponds with the grounded phase, and at the time the voltage on the other two phases will tend to rise toward a value equal to line voltage, that is 1.73 times normal voltage to ground. This overvoltage on the two sound phases is made use of to trip the two corresponding overvoltage relays and thus cause, by their joint closure, the automatic closing of one of the ground switches.

For instance a ground on phase (1) will cause a high voltage on phases (2) and (3). The joint trip of relays R 2 and R 3 will close the ground switch phase (3) thus causing a complete short-circuit between phases (1) and (3) and causing the faulty line to clear on overload. After the faulty feeder is cleared from the system a ground would remain due to the ground switch still being in closed position. In our particular example the ground would remain on phase (3) due to ground switch (3) remaining closed. The overvoltage relays

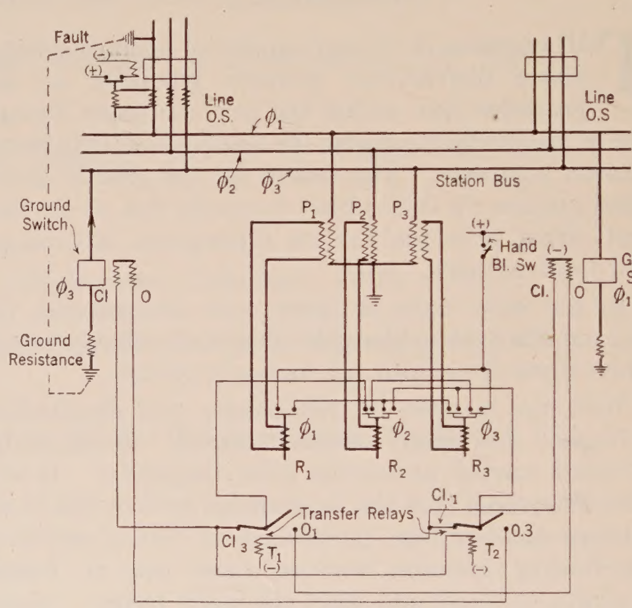

Fig. 1

of phase (1) and (2) would therefore trip and close ground switch (1) thus causing a bus bar short circuit if no special provision were made as by the installation of a transfer relay, to prevent such action.

The transfer relay blocks the closing circuit of the second ground switch immediately upon the closing of the first ground switch, and at same time prepares for the tripping of the ground switch which has been closed. When ground switch (3) closes, it energizes the coil of the transfer relay (T 2) throwing the lever over into the other contact position. In this position of the lever high voltage on phase (1) and (2) due to ground switch (3) being in closed position, will trip the ground switch (3) and thus re-establish normal conditions instead of closing wrongly the ground switch (1). Transfer relay (1) will in a similar manner prevent the closing of ground switch (3) and assure the opening of ground switch (1) when overvoltage relays R 2 and R 3 will

1. Original description in "Relay Protective Features of the Toronto Power Co's. Transmission and Distribution System" by P. Ackerman, *Journal, Engineering Institute of Canada*, April, 1921.

trip after a ground on phases (2) or (3) has been cleared, leaving ground switch (1) closed.

The above is a description of the essential features of the ground selector.

Various other features had to be embodied to make the device practical. These additional features are not shown in the schematic diagram but may be briefly discussed in the following:

The sketch shows three overvoltage relays only, and no provision to prevent these relays tripping on three-phase overvoltages, as may occur from various reasons. Such action would not be harmful in itself, since none of the ground switches would be able to close. The closing circuits would be ruptured instantly by the transfer relays upon the initial energizing of the circuits. However, their action would unnecessarily alarm the operator and necessitate the re-setting of the device. For this reason a balance potential relay has been introduced which only responds to an unbalance of potential to ground.

This relay keeps the actuation of the phase overvoltage relays blocked so long as it is not actuated itself. It therefore prevents the device from getting into action during three-phase overvoltage.

As a precautionary measure for any unexpected action on the part of the ground selector, the ground switches are equipped with overload relays, set sufficiently high for the line protection to clear before the ground switch opens.

As a further precaution, each ground switch is provided with complete electric control which enables the operator to actuate the ground switches by hand, if necessity arises.

A hand blocking switch is also provided by means of which the automatic features of the device can be stopped without, however, interfering with the hand control of the ground switches.

A ground resistance is provided in series with the ground switches. This resistance is purposely made low so as to influence only slightly the magnitude of distant short circuits, but having a tendency to hold up the bus voltage for grounds very close to the station.

The ground selector will operate once only and will have to be reset by hand by moving the transfer relay into the original position before it is ready for new action. This, however, does not cause any inconvenience, and has been found preferable to an automatic resetting which latter might cause trouble should a ground develop into a short circuit and clear the feeder before the ground switch has been closed completely.

From this description it will be noticed that the name "ground selector" is not quite correct, since it is actually the relay protection that selects the ground, whereas the device is a means only to create the condition which will enable the relays to act and select the grounded line. Nevertheless the name was adopted as being the most descriptive.

Comparison of Ungrounded and Grounded Systems

To fully appreciate the problem involved and the advantage derived from the ground selector it will be desirable to compare the characteristic features of grounded and ungrounded system under various operating conditions.

The following table tries to cover in a concise form, the behavior of the various possible operating methods, showing in the last column for each operating condition the scheme which is considered advantageous.

In going over Table I, it will be noticed that most of the items indicate that the ungrounded system equipped with ground selector proves in practically every respect advantageous or equal to the grounded system.

One item only may prove pronouncedly advantageous for the grounded system that is cost of grounding where Y = connected transformers are in existence (see item 26). In this respect it may be pointed out however, that in many instances this saving compared with the cost of a ground selector may be more than offset by other inconveniences such as ineffective relay protection or loss of flexibility in the use of different transformer connections.

Some other items indicate that the grounded system appears to offer some advantage over the ungrounded system equipped with the ground selector.

It will be worth while to further analyze these items.

Item 7 points out the possibility of line switching causing a momentary shifting of the neutral should the three phases not close simultaneously. It is well realized today that damage to insulation is a function of magnitude of voltage and its duration; in other words, it does not only require high voltage, but the voltage must also last a certain time before it actually is able to do damage. A switching surge is of such brief duration and of rather limited voltage magnitude, so that the possibility of serious voltage stresses from switching surges is more problematic than real. Practical experience also plainly shows that troubles are hardly ever experienced at times of switching except in cases of very depreciated insulation which may barely be able to stand normal voltage.

Item 8 points out the fact that solidly grounded systems can have much more sensitivity set arresters than ungrounded systems. This is no doubt an advantage, but in view of the fact of the standard practise of a test voltage of two times line voltage for one minute on all equipment, the general improvement in design of transformer windings to withstand steep wave front impulses and the possibility of sensitive adjustment of arresters close to line voltage, this drawback of the ungrounded system should not be so serious.

Item 12 shows how, in case of the ground selector on the ungrounded system, the overvoltage on two phases created by a ground on the third phase cannot be avoided. The duration of this overvoltage is, however, so short and the overvoltage of such limited nature that any

TABLE I

COMPARISON OF GROUNDED SYSTEM WITH UNGROUNDED SYSTEM EQUIPPED WITH GROUND SELECTOR

Reference No.	Operating Condition	A Grounded System	B Ungrounded System with Ground Selector	Advantageous Scheme
	I Normal conditions (a) Transformer connections.			
1	Flexibility of connections.	Requires Y/Y transformation to enable grounding of all systems. Danger from third harmonics which can only be overcome by tertiary delta winding.	Permits use of any kind of transformer connection. Y/Δ . Δ/Y . Δ/Δ . Λ/Λ No danger from third harmonic.	B
2	Complications involved.	Delta systems have danger from third harmonic eliminated, but require special grounding transformer.	Ground selector equipment adds complication.	
3	Advantage of Y connection.	Star transformer will have larger conductors making trf. mechanically stronger and providing larger electrostatic capacity between turns which improves high frequency stresses. This, however, only important at voltages higher than 60,000 volts.	By using delta connection on low-tension side and star on high-tension, same advantages can be obtained from star winding.	
4	(b) Inductive interference.	Residuals can be reduced but never completely eliminated.	Residuals can be eliminated by proper transpositions.	B
5	(c) Effect from static charges.	Static charges on wires are drained off through ground connection.	Static charges can accumulate. Should effectively be taken care of by corona leakage or effective overvoltage protection.	
6	(d) Voltage to ground.	Phase voltage to ground remains constant, but increased leakage may cause increased local heating and thus rapidly work toward a complete breakdown, since there is not only limited capacity current flowing, but actual dynamic current.	Unbalanced capacity to ground or unbalanced leakage to ground during foggy weather may cause slight shifting of neutral point adjusting to a new equilibrium. With fair insulation this should not prove serious.	
7	(e) Effects from switching.	Phase voltage to ground will remain constant.	Switching is liable to shift neutral when individual phases close slightly in succession.	A (apparently)
8	(f) Setting of arresters.	Arresters can be set in relation to fix ground voltage, which will be lower than on ungrounded system. Setting therefore, more effective.	Arresters must be set in relation to line voltage to avoid discharge in case of ground.	A (apparently)
	II Abnormal Conditions.			
	(a) Effect on system.			
9	Permanent ground (1 wire to ground.)	Develops instantly into short. Faulty feeder is cleared by relay causing partial interruption.	Ground operates ground selector. As a result short circuit develops. Faulty feeder is cleared by relay causing partial interruption.	
10	Self-clearing momentary ground. (1 wire to ground).	Develops instantly into short. Will actuate relays and cause partial interruption. Interruption may be saved by arc extinguisher, but short-circuit disturbance cannot be avoided.	If ground clears before ground selector switch closes, no dynamic voltage disturbance will result and in consequence no interruption to any part of the system.	B
11	Short circuit between phases.	Short circuit will be cleared by relays.	Short circuit will be cleared by relays.	
12	(b) Voltage stresses in case of ground. (1 wire to ground).	With solidly or low-resistance grounded neutral no extra voltage stress is exerted on any of the windings.	The ground causes a voltage rise to full line voltage on sound phases for about half second until ground selector switch is closed. After the short-circuited feeder is cleared, the ground left on the system by the closed ground selector switch, will cause again opposite phases to rise to full voltage for ¼ sec. until ground switch has opened.	A (apparently)
	(c) Inductive interference.			
13	Ground (1 wire to ground)	Short circuit with ground return will create heavy electro-magnetic interference to telephone lines. This cannot be prevented, but damage can be reduced by clearing short circuit by quick relay action.	The electrostatic interference, preceding the short until ground selector switch closed, will be small. The short circuit which follows will have the same serious effect as in case of grounded system.	

Reference No.	Operating Condition	A Grounded System	B Ungrounded System with Ground Selector	Advantageous Scheme
14	Short between phases without touching ground.	Inductive interference will be small because of the neutralizing effect of feed and return wire.	Same condition as on grounded system.	
15	Shorts of two phases through ground.	Will constitute two single phase shorts 120° out of phase with resultant current passing back through ground to grounded neutral. Will result in heavy electro-magnetic interference.	Will constitute a single-phase short with metallic return so that inductive interference becomes neutralized.	B
	(d) Permissible emergency conditions.			
16	Disabled single phase transformer.	Y/△ Transformers can be operated with one trf. disconnected, if step-up and step-down transformers have grounded neutral. This condition, however, will create serious electrostatic and electro-magnetic interference.	△/△ Transformers, if using single-phase units, will permit operation on open delta, with one single-phase transformer disconnected.	B
17	Disabled line wire.	Y Permits operation with two wires only, provided step-up and step-down transformers have grounded neutral. Creates, however, serious electro-static and electro-magnetic interference.	△ Could be operated with two wires if ground was used as third wire. Voltage between wires and ground would be increased by 73 per cent. Arrangement would create serious electrostatic and electro-magnetic interference.	A Advantage in exceptional cases only.
18	(e) Danger of secondary breakdowns in case of a ground.	No such danger because of fixed voltage to ground.	Hazard of cross short circuit very small because of ground condition lasting only for a very brief period.	A (apparently)
19	(f) High-resistance ground.	Occasionally high resistance grounds develop. Only 58 per cent of normal line voltage will be across the fault causing danger of insufficient current to actuate relays.	Ground selector when closing will throw full 100 per cent line voltage across fault, so that current will be 1.73 times greater, under similar conditions than in case of grounded neutral. As result more definite relay action is assured.	B
20	(g) No. of troubles.	Larger number of voltage disturbances and partial interruptions is to be expected since every ground represents a short circuit.	Smaller number of voltage disturbances and partial interruptions is to be expected since momentary self-clearing grounds not affecting system.	B
21	(h) Adaptability to existing systems.	Y-Connected transformers permit easily grounding of neutral point.	Ground selector can be easily installed on bus-bar of one of main stations irrespective of existing transformer connections.	
22		△ Systems require special kind of grounding scheme, which will be particularly expensive if to be of low impedance to assure sufficient current for relay action.	Ground selector can be easily installed on bus-bar of one of main stations irrespective of existing transformer connections.	B
23	(i) Limiting effect on system in case of ground.	Disturbance can be limited by ground resistance or high impedance of grounding transformer as far as relay protection will permit.	Disturbance can be limited at liberty by ground resistance in circuit with the ground selector switches.	
24	(k) Short circuit stresses on equipment.	In case of all transformer neutrals of parallel operated transformers being grounded, the short-circuit stress will be equally distributed between all the transformers.	Ground selector providing a direct short circuit across phases of the system will divide the short-circuit stress equally among parallel operated transformer and generator equipment.	
25		Where only one generator or one transformer is grounded or where special grounding transformer is used, the total short-circuit stress will have to be taken up by the respective unit.	Ground selector providing a direct short circuit across phases of the system will divide the short-circuit stress equally among parallel operated transformer and generator equipment.	B
26	(l) Cost.	Where transformers are star-connected so that system can be grounded by grounding the transformer neutral, the expense will be very small.	The ground selector will require oil switches, potential transformers, ground resistances and some relay equipment which will involve a smaller or larger expenditure depending on the operating voltage.	A
27		Where a special grounding equipment must be provided, the expense may become considerable.	The ground selector will require oil switches, potential transformers, ground resistances and some relay equipment which will involve a smaller or larger expenditure depending on the operating voltage.	

fair insulation of the system should be able to resist this stress without harm. Nevertheless the fact remains that this condition is liable to invite cross short circuits to some weak point of the system (see Item 18). The insulation giving thus away, however, would have to be so weak that such cross short circuit and the weeding out of such point would only be desirable. Operating results of the ground selector bear out the above contention.

Regarding the danger of high-frequency surges created by an arcing ground at the point of fault, it may be pointed out that in the writer's opinion the existence of the arcing ground should be extremely rare.

Puncture of insulation, be it puncture of an insulator or a cable, most frequently cause permanent grounds. In either case the current passes through a very occluded and short path, so that the heat concentration is enormous and in consequence the local resistance of the path must be zero and paramount to a solid ground. In case of a punctured cable the heat must also instantly char the organic insulation so that a carbonized short-circuit path will be formed.

The only conceivable conditions which may create arcing grounds would be a puncture under oil or an open arc over a broken insulator or any gap the breakdown point of which would just about correspond to the line voltage or surge voltage. Under such condition the arc would naturally become very unstable and would thus be able to form an arcing ground. The experience with the ground selector does not indicate any danger from this source, not even in cases of swinging grounds which sometimes are causing arcs at intervals of a few minutes, and which no doubt create the most unstable arc.

Operating experience with the ground selector indicates that the disadvantage of momentary overvoltage on the sound phases is practically negligible except in case of very depreciated insulation.

Item 17 indicates the advantage of the star grounded system of permitting maintaining operation over two wires using ground as return wire. Inductive interference from such method of operation will be so serious that this method could only be applied in special cases where the lines are running in isolated territory far away from telephone and telegraph lines.

From the above it will be noticed that the few items which appear to speak for the grounded system are of minor importance and turn out to offer in actual practise a very small advantage over the ungrounded system equipped with ground selector.

From the foregoing it follows that the most important advantages of the ungrounded system combined with ground selector, compared with grounded system, are:

a. Flexibility in the use of transformer connections.

b. Reduced number of system disturbances and partial interruptions because of the ability of momentary grounds to be self clearing.

c. Easier adaptability of the ground selector, particularly to existing systems, with delta-connected transformers.

d. Prevention of concentrated short-circuit stresses on individual apparatus, such as might be the case with special grounding transformers or in systems where only individual apparatus are grounded.

e. Reduced inductive interferences.

f. Increased voltage across the point of fault which is particularly advantageous in case of long lines to supply sufficient ground current despite the increased reactance due to the ground return circuit; in case of high-resistance grounds the higher dynamic voltage will also assist in breaking down the fault sufficiently to supply current for effective relay action.

Operating Results

Hereafter two cases are described where the ground selector has been effectively in service for a few years. The two cases are particularly interesting in that they represent about the most extreme cases of type of distribution and voltage where the ground selector may be applied. A brief description of the respective systems and the reasons for adopting the ground selector are given in each case.

12,000-Volt Toronto Distribution of the Toronto Power Company

Fig. 2 shows a single line diagram of the distributing system. The power is received at 90,000 volts and is stepped down to 12,000 volts by Y/Δ transformer banks, the low-tension system being operated ungrounded.

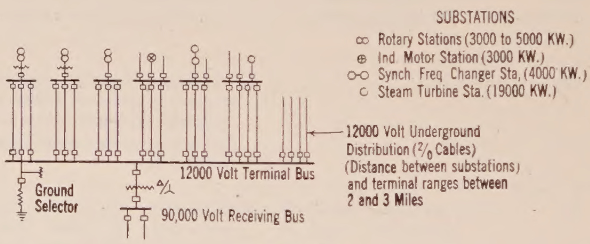

Fig. 2

The 12,000-volt distribution consists of about 80 miles undergrounded cables and about 80 miles overhead lines. All overhead lines are wooden pole construction with wooden cross-arms and ungrounded steel pins and some of them are of considerable length, passing out into rural districts. Grounds were quite frequent, many of them being self clearing without causing any disturbance to the system. Permanent grounds, however, always caused serious disturbances and interruptions to the system until located. On several occasions the system was completely paralyzed due to secondary breakdowns developing on account of the overvoltage on the opposite phases created by a ground.

In fact such secondary breakdowns or so-called cross-short circuits were so much feared, that the practise established itself that the whole station was

cleared immediately upon indication of a permanent ground, and then the system was started again by closing one feeder at a time, leaving out the feeder, which made the ground reappear. With this procedure secondary breakdowns could usually be avoided although it meant a complete shutdown of the system.

It was realized that something had to be done to improve this situation and it was then that the idea of the ground selector developed. This was as far back as 1916. It was realized, however, that the scheme would only be beneficial if the overload protection of the distribution were effective and dependable. In an endeavor of putting first the short-circuit protection of the distribution into shape, the installation of the ground selector was delayed until September, 1918.

The main reasons in this particular case for adopting the ground selector in preference to some permanent grounding scheme were as follows:

1. The ground selector was cheaper and simpler to install, since existing spare feeder switches could be used for the purpose and since the ground current could be adjusted to any desired value to suit relay requirements.

A grounding scheme would have involved either a costly grounding transformer of very low impedance to ensure sufficient current to actuate the ordinary overload protection, or a less costly grounding transformer of higher impedance, in which case however the ground current would have been so limited that a special ground protection would have been required which in itself would have offered serious difficulties and expense if the same selectiveness and effectiveness was to be obtained for grounds as for shorts circuit.

2. The ground selector promised, for reason of the time lag, of closing the ground switch, to allow self clearing grounds to clear without disturbance to the system.

It was originally intended to provide dead artificial grounds, so as to obtain identical current conditions for grounds and short circuits to assure effective relay action under all conditions. However, it was finally decided to introduce a very low ground resistance in form of a large water rheostat which hardly affected the magnitude of the fault current under most limited current conditions in case of distant grounds, but which offered the great advantage of keeping up the bus-bar voltage for grounds close to the terminal station, thus helping to keep the synchronous load in step.

The ground selector was put in service in 1918 and has proved very effective and beneficial as following operating records will indicate:

Table II shows an operating record of the ground selector, showing the number and kind of troubles it had to clear.

Table III shows a summary of troubles experienced on the 12,000-volt distribution. This table indicates particularly the large number of self-clearing grounds without disturbance to the system, which shows a decided advantage over a permanently grounded system.

It may be pointed out that since the installation of the ground selector not a single secondary breakdown, causing a cross short circuit to some other point of the system, has been experienced.

TABLE II

OPERATING RECORD OF GROUND SELECTOR OF 12,000-VOLT TORONTO DISTRIBUTION

	Sept. to Dec. 1918	1919	1920	1921
(A) Grounded feeders effectively cleared by action of ground selector and respective feeder protection.				
1. Permanent troubles.				
Cable troubles		4	1	1
Bad insulators		4	4	1
Bad apparatus (current transformers, Power transformers, oil switches, etc.)		5	6	3
Operator's fault		1		1
Miscellaneous		2		
Total permanent troubles		16	11	6
2. Transient troubles.				
Lightning		3	4	3
Unknown	6	15	15	19
Miscellaneous	1			4
Total transient troubles	7	18	19	26
Total of grounded feeders cleared	7	34	30	32
(B) Momentary self-clearing grounds, starting ground selector without developing into short circuit.				
1. Ground switch closing and opening momentarily	4	10	10	26
2. Momentary ground relay energization of too short duration to start ground selector switch	2	7	8	13
Total self-clearing grounds	6	17	18	39
(C) Testing faulty feeders		5	15	3

TABLE III

SUMMARY OF TROUBLES OF 12,000-VOLT TORONTO DISTRIBUTION

	1919		1920		1921	
	N	Per cent	N	Per cent	N	Per cent
1. Grounds cleared by ground selector	34	30	30	31	32	23
2. Grounds, self-clearing, without disturbance to voltage and without partial interruptions	17	15	18	18	39	29
3. Short circuits	63	55	50	51	66	48
Grand total	114	100	98	100	137	100

In all cases the trouble and partial interruption remained confined to the faulty feeder.

With the exception of one case the nature of the ground was always of sufficiently low resistance to produce sufficient ground current to effectively trip the relays. In the case which did not clear the feeder the ground current was sufficient to be distinctly noticed as overload on the respective line ammeter, enabling the

operator to clear the feeder by hand without serious disturbance to the system.

In practically all cases the grounded feeders were cleared without serious disturbance to the load and without dropping other load than the one of the feeder in trouble.

In two cases 30 per cent to 50 per cent of the whole system load was lost, but in both cases the reason was that the arc produced by the ground current at the point of fault spread into the other phases and thus caused a three-phase short circuit before the feeder had time to clear.

The ground selector has proves fully up to expectation in eliminating cross short circuits and offering a means to effectively clear grounded feeders without interruption to other parts of the system.

It has, moreover, simplified operation of the Toronto distribution since it permits parallel operation of the whole distribution at all times, whereas before, the system had to be sectionalized whenever a ground occurred in an endeavor to sectionalize and localize the ground.

50,000-Volt 30 Cycles Distribution System of the Shawinigan Water and Power Company

Fig. 3 shows a single wire diagram of this system. It is of a completely different nature to the Toronto system.

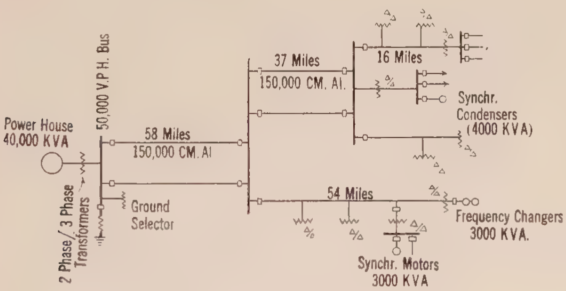

Fig. 3

The lines were of the first ones built at this voltage. The lines are of wooden pole construction with wooden cross-arms and wooden pins. Each pole is grounded by a ground wire running down the pole and being wound around the butt of the pole. The insulator pins, however, are not grounded. No overhead ground wire is provided. The ground at each pole is therefore entirely dependent on local ground conditions. The 50,000-volt system is fed from a two-phase power house by means of Scott-connected step-up transformers.

Grounds were causing serious tie-ups due to general weakening of the old insulator.

Grounding of the system was then seriously considered to eliminate this serious state of conditions, but in going further into the matter preference was finally given to the ground selector.

It would have been comparatively easy to tap the neutral point of the Scott-connected transformers and thus provide a grounded neutral at the power house end.

The double line protection, however, basing on a principle requiring the back feed from synchronous machinery of the receiving end, would have become ineffective for grounds with only the generating station neutral being grounded. To make the double line protection effective also for grounds would have necessitated change to star-connected transformers with neutral grounds at all stations with synchronous machines. This was not considered desirable since it would have eliminated the possibility of running the transformer bank open delta in case of trouble in one of the single-phase units. The ground selector on the other hand assured proper double line protection without need of any change in the existing layout.

A further important point in favor of the ground selector was the fact that it produced 1.73 times greater voltage across the point of fault compared with a grounded neutral system.

It was felt that this increased voltage would materially aid in completing any insulation breakdown to a state of low-resistance ground and would assist in increasing the ground current, thus assisting effective relay action. This was considered particularly important in view of the uncertain ground conditions and in view of the very long lines with excessive reactance drop which tended to limit the fault current.

The ground selector was installed in September, 1919, and the following gives an operating record of the device:

TABLE IV

OPERATING RECORDS OF GROUND SELECTOR OF 50,000 VOLT SHAWINIGAN SYSTEM

	Sept. to Dec. 1919	1920	1921
(A) Grounded lines effectively cleared by action of ground selector and respective line protection.			
1. Permanent troubles		7	8
2. Transient troubles		12	13
Total of grounded lines cleared	8	19	21
(B) Momentary self-clearing grounds. Starting ground selector signal only, without short, or closing ground switch causing a momentary self-clearing short circuit		10	9
(C) Testing faulty feeders	5	7	1
(D) Grounds, where ground selector unable to clear line either because of high-resistance ground or because of ground selector not locking when closing		1	2
(E) Grounds developing into cross short circuits due to harmless flashover		26	11

Table IV gives a summary of the actions of the ground selector.

Table V shows the number of troubles cleared by the ground selector in relation to the number of other troubles.

It will be noticed that the results do not look as satisfactory as those shown in Tables II and III.

Considering however the character of the system, it must be realized that the results are rather better than expected.

The momentary self-clearing grounds are of a smaller percentage than in case of Table III of the 12,000-volt system, so that the advantage compared with a permanently grounded system is not so pronounced.

High-resistance grounds, where the ground selector was unable to produce sufficient current to operate relays are also somewhat more numerous than in case of the Toronto system. There were however only three cases of this nature compared with forty-eight cases where sufficient ground current was developed to actuate relays, which means only 6 per cent ineffectiveness. In view of the uncertain ground condition along the line this must be considered an unexpectedly good result.

TABLE V

SUMMARY OF TROUBLES OF 50,000-VOLT SHAWINIGAN SYSTEM

	1920		1921	
	N	Per cent	N	Per cent
Feeders cleared by ground selector	19	14	21	22
Momentary self-clearing grounds	10	7	9	9
Grounds where ground selector not effective	1	1	2	2
Grounds developing into cross short circuits but without permanently disabling line	26	19	11	12
Short circuits	81	59	53	55
Grand total	137	100	96	100

The number of secondary breakdowns, causing a cross short circuit to some other part of the system is, as seen from Table V, still undesirably large. It is to the credit of the ground selector, however, that only one of these cross short circuits actually caused a permanent insulation damage. All other cross short circuits were harmless flashovers traceable to asbestos mining districts caused by insulators whose flashover had been reduced by a combination of broken skirts from blasting and asbestos dust coating having become moist from fog or slight rain. Considerable trouble from flashovers in this district is experienced under normal voltage conditions and it is well known that sometimes insulators may be on the system unobserved which may barely be able to resist the normal operating voltage; so that the least voltage disturbance will cause the insulators to flashover.

The large number of cross short circuits is therefore less an indication of a weakness of the ground selector in that respect than a weakness in the insulation of the system at these points and has to be remedied by increasing the local safety factor of flashover even under conditions of broken skirts.

The operating results of this system indicate, similar to the Toronto system, the ability of the ground selector to avoid secondary breakdowns, as long as the system has only fair insulation, and to provide sufficient current to effectively clear faulty lines.

Conclusion

The operating results show conclusively that the ground selector will improve the ungrounded system to the same state of perfection as claimed for the grounded system without having to resort to an artificial grounding method.

The operating results show that the ground selector prevents permanent secondary breakdowns and permits clearance of grounded lines as effectively as the grounded system. Besides this, the ungrounded system retains the advantage of less numerous voltage disturbances and partial interruptions and the flexibility of permissible transformer connections.

The ungrounded system, combined with ground selector and equipped with an effective relay protection should prove therefore advantageous compared with the grounded system, at least as far as large distributing systems are concerned and for voltages, not exceeding 60,000-volts.

This conclusion does not necessarily apply to parallel trunk lines where grounded neutral at both ends may prove cheapest and best.

It also does not apply to any system exceeding 60,000-volts since the complication and cost may become excessive.

Each individual case, of course, will have to be studied on its own merits to arrive at a conclusion of the most desirable arrangement.

COMMERCIAL BROADCASTING IN GERMANY

After four months of experimenting, the Express Service Company (Eildienst Gesellschaft) Berlin, has begun a daily service of financial and commercial news broadcasting to subscribers in various parts of Germany, according to a report to the Department of Commerce from Consul E. V. Richardson, Berlin. This company is financed by German capital and is purely a private undertaking. Having arranged with the national government for the use of the radio station at Koenigswusterhausen on a limited basis for a definite period, a regular service of financial news is received from the United States, Switzerland, Sweden, and other c untries, via the high power station at Nauen, Germany.

This information is broadcasted immediately by radio telephone to subscribers of the company. These number at present about 800 and are mostly banks and industrial institutions located in some 200 towns and cities. It is expected that New York quotations handled by this service will be available generally to subscribers within ten minutes of their dispatch.

Each subscriber rents from the company the necessary receiving apparatus, paying for the service itself an annual fee of 300,000 marks, and for the apparatus an annual rental of approximately 200,000 marks. There are two ½-hour schedules daily, beginning at 9:30 A. M. and 5:00 P. M.

Machine Switching Telephone System for Large Metropolitan Areas.

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Review of the Subject—*From the earliest forms of telephone switchboards to the modern types, the development of the switchboard has been marked by the increasing use of automatic methods to supplement the manual operation wherever this would result in better service to the public or more efficient operation.*

In addition to all that has been done in developing and introducing automatic operations with manual switchboards, it has been found desirable and practicable to go further in the direction of introducing automatic operation in the telephone plant and a machine switching system has been developed in which the bulk of the connections are established without the aid of an operator.

The complexity of a large metropolitan area and the exacting requirements which a machine switching system must meet are outlined briefly, and the system which has been developed to meet these requirements is described.

The application of the system to a typical large metropolitan area and the means provided for permitting its gradual introduction into the existing plant are discussed.

IT is the purpose of this paper to outline briefly certain important developments in connection with machine switching telephone systems and to discuss the application of the results of these developments to the problem of providing telephone service in large metropolitan areas.

The telephone was invented in 1876. Amost immediately thereafter it was recognized that, for it to attain its greatest field of usefulness, switchboards and switching centers would have to be established for effecting interconnection between subscriber's lines.

Professor Bell's vision of the future was given in a statement to prospective investors. He said:

"It is conceivable that cables of telephone wires could be laid underground, or suspended overhead, communicating by branch wires with private dwellings, country houses, shops, manufactories, etc., etc.—uniting them through the main cable with a central office where the wires could be connected as desired, establishing direct communication between any two places in the city. Such a plan as this, though impracticable at the present moment, will, I firmly believe, be the outcome of the introduction of the telephone to the public. Not only so, but I believe in the future wires will unite the head offices in different cities, and a man in one part of the country may communicate by word of mouth with another in a distant part.

"Believing, as I do, that such a scheme will be the ultimate result of the telephone to the public, I will impress upon you all the advisability of keeping this end in view, that all present arrangements of the telephone may be eventually realized in this grand system."

Early Developments

The only apparatus available at that time for this purpose was that employed in telegraph, messenger, fire and burglar alarm services. Some of this apparatus, such as wire, insulators, batteries, annunciators, etc., was found to be useful in the new art; other apparatus had to be developed. The switchboards of that day employed this apparatus. They were small in size, and could accommodate only a limited number of lines.

It soon became evident that the requirements of the telephone exchange service demanded signaling and switching equipment different from that employed in any of the other branches of the electrical industry, and it became necessary to create an entirely new art, involving many branches of science, before commercial telephone service could be given on an adequate scale.

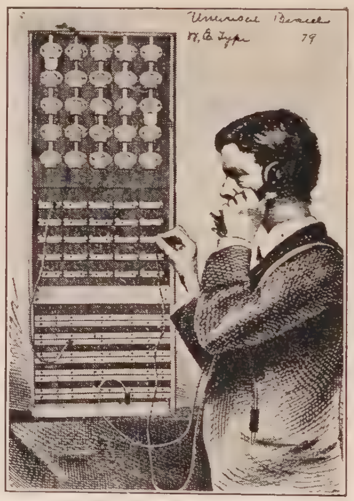

Fig. 1—Early Type Switchboard

The switchboards grew from small boards, capable of handling a few lines, as shown in Fig. 1, to the very complex arrangements providing signaling, switching, and transmission facilities for as many as ten thousand lines in a single board, of the type shown in Fig. 2.

As the subscribers increased in number it was found that beyond a certain point it was no longer practicable or economical to have all of the subscribers' lines brought to one center. It was therefore necessary to have several centers, the number depending upon many

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factors, the most important of which are the size and telephone needs of the community.

The consequence of all this is that in large metropolitan areas the number of centers is large, and the trunking system complex, as each center must be provided either directly or indirectly with trunks to every other center.

As an illustration, take the New York Metropolitan area, shown in Fig. 3, where the telephone plant is of

Fig. 2—Modern Type Common Battery Switchboard

the greatest intricacy because of the very large number of subscribers served. There are at the present time 158 central office switchboards, many of them having equipment for 10,000 lines. These offices and the associated plant provide for intercommunication between 1,400,000 telephones, and approximately two

Fig. 3—Map Showing Location of Central Offices in New York Metropolitan Area

trillion possible connections. It is estimated that by the year 1940 there will be 300 central office switchboards within the New York Metropolitan area, serving some 3,300,000 telephones—or nearly two and a half times the present number.

Manual Switchboards

The system most commonly employed today for connecting subscribers' lines together is the so-called "manual" system; that is, a system in which operators are employed to make the actual connections between subscribers' lines, although so many of the functions are performed automatically that, except in name, it is to a large degree automatic.

It is a long step from the early switchboards to the modern common battery multiple manual switchboards. The history of the development of switchboard equipment and apparatus shows that enormous progress has been made in this art in a comparatively few years. As the telephone subscribers have grown in number and as the amount and complexity of the traffic have increased, it has been only by the most intensive development that it has been possible to keep ahead of the demand for telephone service, and that telephone engineers have been able to get the speed, efficiency and accuracy that are obtained today in so-called manual operation. It is worthy of note in this connection that the attainment of these ends was made possible by the extensive introduction of automatic features.

A very brief description at this point of the type of manual switchboard more commonly employed will be helpful.

In this switchboard the subscriber's line terminates at the central office in so-called "jacks." Associated

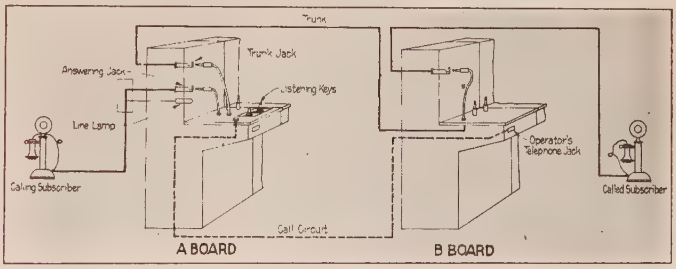


Fig. 4—Diagram Showing Manual Interoffice Connection

with each line is a lamp, individual to it, which automatically lights when the subscriber removes his receiver from the hook. This serves as a signal to the operator that a connection is desired.

The operator answers this call by inserting one end of a cord in the jack associated with the calling subscriber's line, operates a listening key which connects her telephone set to the subscriber's line, and asks for the number desired. When this is obtained the operator completes the connection by inserting the other end of the cord in the jack of the desired subscriber's line, and the subscriber's bell is rung. Suitable lamp sig nals are provided so that the operator may know when the called subscriber answers, when either subscriber desires further attention, or when either or both of them have finished talking and have hung up their receivers.

If the subscriber desired is connected to a distant office, the operator receiving the call would, instead of

plugging directly into the subscriber's line, directly connect the subscriber's line to a trunk terminating in the desired office, where the connection would be completed by a second operator, known as the "*B*" operator, as shown in Fig. 4. Such communication between the two operators as is necessary to establish this connection takes place over a special pair of wires known as a "call circuit."

The method, of which the above is a bare outline, is that used in completing ordinary connections. Different arrangements and different operating methods have to be provided for handling short haul toll calls, long distance calls, calls from coin boxes, and calls of many other kinds.

In the simplest types of manual systems, the subscriber, in order to signal the central office, turns a crank thus operating a magneto generator. This throws a drop in front of an operator at the central office. In the switchboards developed to meet the needs of the larger areas, electric lamps are substituted for the drop, and relays automatically controlled by the subscriber bring them into play at the proper time. Electric lamps which serve as visual signals to the operator to indicate the status of the connection are also associated with the cords that the operator uses for connecting subscribers together. The operation of these lamps is automatic and is under the control of the switchhook at the subscriber's station.

Many other arrangements of an automatic character have been developed and are used as occasion requires—not merely because they are automatic in character but only when it has been established that they make for better service to the public or for efficiency and economy of operation, or both. Among these may be mentioned automatic ringing, automatic listening, and many forms of automatic signaling. Many of these arrangements are highly ingenious and contribute greatly to the efficiency and economy of operation. Thus, the trend of switchboard development has been more and more in the direction of automatic operation and automatic methods.

In addition to all that has been done in developing and introducing automatic operation with so-called manual switchboards, it has been felt for a long time that in large and complex telephone areas, such for example as New York City, the time would ultimately come when it would be desirable to go further in the direction of introducing automatic operation in the telephone system. This whole matter has been the subject of much thought on the part of engineers of the Bell System and, as a result, there has been developed and recently put into operation a system in which the work of establishing most of the local connections is done entirely by machinery.

The introduction of this system will eventually make a considerable reduction in the telephone company's requirements for operators which are becoming more difficult to fulfill year by year. Operators will be required, however, to handle toll and many special classes of local calls and for this reason, together with the constant growth of the business and the considerable period of time that will be required to introduce the new system completely, we can expect little or no reduction in the present operating forces for some time to come, and no operator will find herself out of employment on account of the introduction of the machine switching system.

Machine Switching

It is the purpose of this paper to describe this system sufficiently in detail to give a general picture of it, but because of the limitation as to space no attempt will be made to go into the intricacies of circuits and apparatus, which doubtless would be of interest only to the telephone engineering specialists.

Among other requirements, the following must receive special consideration in the design of a machine switching system.

The functions to be performed by the telephone subscriber in getting a connection must be simple and easily understood.

It must work efficiently and with accuracy and speed, and of course must be capable of handling the various types of calls that the subscriber wishes to make.

The system must not require modifications in the existing rate structure, otherwise than desirable. If the rate structure calls for message register operation, coin boxes, etc., means must be provided for automatically operating the register and collecting the coins on such calls, and for preventing a charge on calls not answered, calls for free lines, busy lines, etc.

The system should employ, as nearly as practicable, the conventional numbering scheme.

It should work with the existing telephone network, so that its introduction does not require wholesale number changes and extensive rearrangement or the abandonment of existing switchboards or other plant. Its introduction must, of necessity, be on a gradual basis.

It must be sufficiently flexible in design to care for growth and such changing traffic conditions as occur from time to time.

In large telephone areas, such as the New York Metropolitan area, there is a great variety of calls to be handled and many different classes of service furnished the public, such as message rate, flat rate, official, coin box, non-attended pay station, attended pay station, special services such as information, etc. Not only individual lines but party lines, and private branch exchanges must be cared for, and provision must be made for thousands of toll messages which must be recorded, supervised and timed.

A call originating in a machine switching office in New York City may have as its destination any one of a great number of points. It may be for another subscriber in the same office or for one in another nearby

machine switching or manual office; it may be for one of a large number of surburban toll points, or it may be to some point in a distant city.

The machine switching system, which is the subject of this paper, meets these requirements. After long-continued laboratory experiments, supplemented by field trials, power-driven apparatus of the panel type has been found to be the most suitable, and is now in successful operation in New York City and in other large cities in the country.

General Plan of Operation

At the expense of some repetition it seems desirable, in order to give as clear an understanding as possible

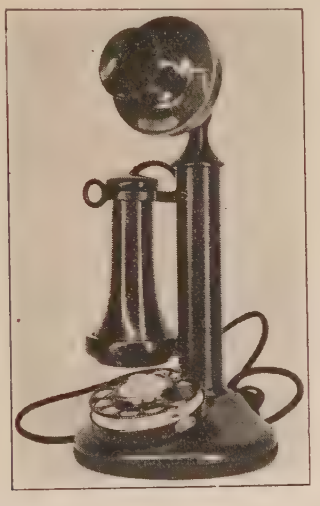


Fig. 5—Desk Stand Equipped with Dial

as to the operation of the system, to first give a brief outline of how the call is handled and a description of the more important elements of the equipment, before going into a detailed description of the operation of the system.

The subscriber's station is equipped with the usual form of telephone instrument and, in addition, with a

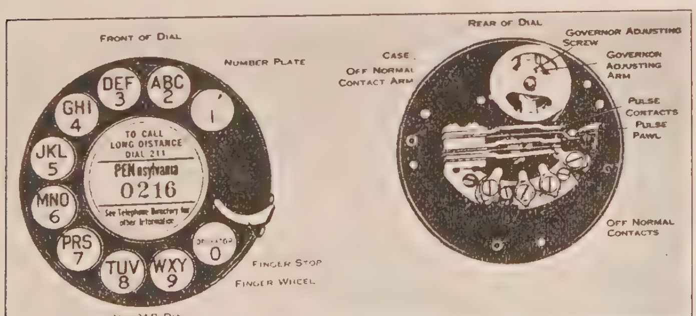


Fig. 6—Subscriber's Dial

calling device known as a "dial," mounted at the base of the desk stand, as shown in Fig. 5. This dial has ten finger holes bearing letters and figures, as shown in Fig. 6.

In making a call the subscriber will, of course, first refer to the telephone directory. He will find in the directory a listing that is only slightly different from that to which he is accustomed. Typical samples of this new form of telephone listing for New York City are shown in Fig. 7. As will be noted, these conform to the present manual listings, except that the first three letters of the office name are set out prominently. This numbering system will be discussed later in this paper.

Having secured the desired telephone number from the directory, which we will assume is "ACAdemy 1234," the subscriber will first remove his receiver from the hook and will hear the so-called "dial tone," which indicates that the apparatus is ready to receive the call. He will then insert his finger in the hole over the letter *A*, rotate the dial until the finger comes in contact with the metal stop shown in the picture, then release the dial, which will automatically return to normal. He will repeat this operation for the letters *C* and *A*, and in turn for the four numerals, *1, 2, 3, 4*.

This operation of dialing on the part of the subscriber is exactly the same, whether the telephone number he desires is in a manual or in a machine switching office.

Argent Co, 1400 Bway..............**GRE** eley 5513
Argentina Brazil & Chile Shipping Co
70 Wall.**HAN** over 0307
Argentine Genl Consulate, 17 Batry pl..**REC** tor 6948
Argentine Impt & Expt Corp, Prod Ex...**BRO** ad 1768
Argentine Mercantile Corp, 42 Bway.....**BRO** ad 5066
Argentine Naval Commission, 2 W 67..**COL** mbus 5623
Argentine Quebracho Co, 80 Maiden la....**JOH** n 1652
Argentine Railway Co, 25 Broad.......**BRO** ad 1383
Argentine Trading Co, 1164 Bway......**MAD** Sq 1871
Argeres Bros, Restrnt, 86 6th av......**SPR** ing 5337
Argero A, Grocer, 119 9th av........**CHE** lsea 6255
Arghis A, Tobacco, 74 Wall.........**HAN** over 6311
Argirople Theodore, Jwlr, 406 8th av..**FAR** ragut 9772
Argo Packing Corpn, 705 Greenwich...**FAR** ragut 4505
Argon Dress Co, 24 E 12..........**STU** yvsnt 2011
Argonaut Supply Corp, 50 Union sq..**STU** yvsnt 7476
Argonne Steamship Co, 17 Battery pl...**REC** tor 2493
Argos Ad-Art Co, 1133 Bway........**FAR** ragut 5986
Argosy The (A Pub), 280 Bway......**WOR** th 8800

Fig. 7—Typical Examples of New Form of Listing Telephone Numbers

Similarly, the method employed by a subscriber who is connected to a manual office in getting a subscriber connected to a machine switching office, is the same as though the desired subscriber were connected to another manual office.

The progress of a call originating in a machine switching office is briefly as follows:

As will be seen from Fig. 8, the line of the calling subscriber, whom we will assume to be a subscriber in the Academy office, appears in a so-called "line finder" frame. When the subscriber's receiver is removed from the switchhook preparatory to dialing, the line is selected by a "line finder" and connected to an idle "sender" by means of a "sender-selector."

Upon completion of these operations which take but a fraction of a second, the dial tone is sent out to the calling subscriber as previously mentioned. When the subscriber dials, electrical impulses on a decimal basis are transmitted to the sender which receives and registers them, translating them in turn to the proper

basis for the control of the selectors which are not operated on a decimal basis. The sender automatically causes the particular "district selector" which is permanently associated with the line finder originally used, to select a trunk to the office desired.

Assuming that the call is for a subscriber in the same office, Academy, the trunk chosen will terminate at an "incoming selector" frame and the sender above referred to will cause the call to be routed through the incoming selector to a final selector, and thence to the particular line desired. When the connection is thus completed, audible signals will be sent back to the calling subscriber to indicate that the station is being rung or that the line is busy.

If the call had been for a subscriber in another machine switching office, namely, Pennsylvania, the call would be routed from the district selector to the office desired, either directly or through an "office selector" in case the total number of trunks to all offices is too large to be placed on the district selector mulitple.

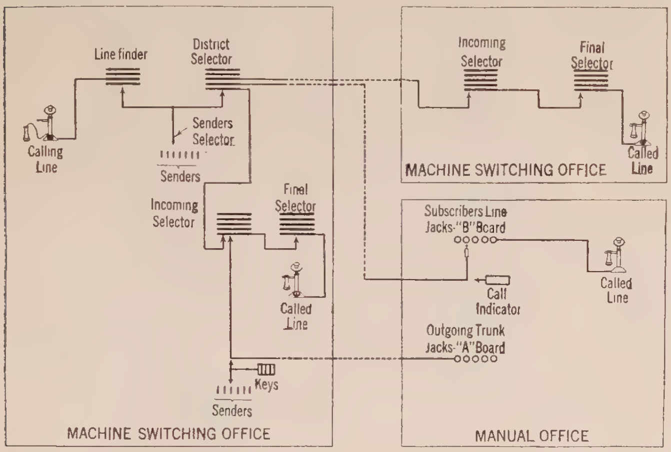


Fig. 8—Diagram Showing Connections from Machine Switching to Machine Switching, Machine Switching to Manual and Manual to Machine Switching.

These trunks terminate on incoming selectors at the Pennsylvania office which select the subscriber's line through final selectors, as described above.

If the call is for a subscriber connected to, say, the Worth Office, which is a manual office, the call would be routed from a district selector directly or through an office selector to the "B" board in the Worth Office, where the number desired appears in front of the operator at a "call indicator position" in the form of visible numbers on the keyshelf. The operator is advised of the trunk to which the call is connected by suitable signals, and the call is completed by plugging this trunk into the desired subscriber's line.

Calls originating in a manual office and intended for a machine switching office reach the machine switching office over trunks from the "A" operators in the manual office. At the machine switching end these trunks terminate in incoming selectors, which have access to the final selectors on which the subscriber's lines are located. The selectors are under the control of a special group of senders, and operators are provided with suitable keys for setting up in these senders the number of the desired subscriber. These operators at the machine switching office receive the information as to the desired number from "A" operators in the distant manual office, exactly as is done in the case of manual operation.

The introduction of machine switching equipment does not require radical changes in private branch exchanges. The private branch exchange is provided with dials, and calls to the central office are dialed by the private branch exchange attendant or by the extension user in the same way that the ordinary subscriber dials. No change in the private branch exchange is required for handling incoming calls. An idle trunk in the private branch exchange group is selected by the mechanism in the machine switching office, in much the same way as an individual subscriber's line is selected.

Numbering System

One of the unique advantages of the plan developed for designating telephone numbers, to which reference has already been made, is that it does not necessitate the abandonment of the existing manual listings. It requires no change except that the first three letters of the office name are set out more prominently. Simple as this change in the form of listing appears, until it was developed by the Bell System no satisfactory method of designating telephone numbers for machine switching offices in large cities was known.

Many plans had been proposed, to all of which there were serious objections. Some of them required changing the whole system of manual designation, others the use of combinations difficult for the subscriber to use. In small cities a numbering plan employing only digits is sometimes practicable, but in such a large area as we are considering, such a plan would involve seven digits. The subscriber's number would take the form of say 786-3549. Such numbers would be difficult for operators to use and for the subscribers to carry in mind and would require that every subscriber's number in the entire area be changed before the first machine switching office could be cut into service. With the new system, the subscriber's number and office in general remains as before. It is necessary to change only a few conflicting office names in order to make them fit into the system.

Description of the Equipment

A detailed description of each unit employed in this system would be impracticable, in this connection, but a brief description of the more important ones will be of interest.

Sender. The use of the sender makes practicable the introduction of machine switching in large metropolitan areas where, of necessity, the service conditions are extremely complex. It is, in effect, the brains of the system, dealing with the subscriber and controlling the selection until the destination is reached, as an

operator deals with the subscriber and controls the selection in a manual system. The number dialed conveys the same information to the sender in a machine switching system as the number spoken by the subscriber does to an operator in a manual system.

The sender is an arrangement of relays, sequence switches, and selectors, so worked out as to perform the following more important functions:

1. It receives a succession of electrical impulses from the subscriber's dial which are on a decimal basis, stores them and translates them to a non-decimal basis, corresponding to the particular group of lines and trunks that is involved in the path of the call.

2. It controls selecting mechanisms which build up the connection to the called party in such a manner that each mechanism is given the exact time required to perform its functions without any waste of time, independently of the rate received from the dial.

3. It makes the central office designations entirely independent of the arrangement of the trunk groups on the selector frames. This is a very important matter, inasmuch as it allows the selectors to be used to full efficiency. It provides the desired flexibility for growth and permits any desirable rearrangement of the trunks on the selector frames that the telephone company may find desirable at any time.

4. The sender is capable of distinguishing the class of office at which the connection terminates. That is, if the call is to terminate at a mechanical office, the sender will arrange to govern the selection accordingly. If the call is to terminate at a manual office, the sender recognizes this and arranges to send out impulses to the call indicator equipment in the manual office.

5. For the completion of certain calls, traffic conditions require the introduction of tandem centers as discussed later. The sender recognizes calls to be routed via tandem centers and arranges to handle these correctly. The tandem center may be manual or it may be mechanical, and the control must be determined accordingly.

6. Certain senders are arranged to serve lines supplied with coin boxes. These senders are arranged to make a test to determine whether a coin has been deposited and do not allow the connection to be cut through so that conversation can take place until the coin is deposited. If the subscriber does not deposit the coin, after a reasonable time has elapsed the sender connects an operator to the subscriber, and this operator notifies the subscriber of his omission. After the coin has been deposited, the sender allows the called subscriber to be rung and permits the conversation. In case the called subscriber is busy or does not answer, or if the call is to a free line, the sender returns the coin to the calling party. If the called party answers, the sender causes the coin to be collected.

The sender makes a test of the calling line after the subscriber has completed dialing, to insure the deposit of the coin, and recognizes whether a coin has actually been deposited or whether some abnormal condition exists, in which case the call will be routed to an operator who causes an investigation to be made.

7. In large areas, such as the New York Metropolitan area, there are distant points, connection to which requires toll charges. In such cases the subscriber is instructed to dial a special operator who will ascertain his wishes, complete the call, and make the proper charge. Should a subscriber attempt to dial outside of his own local service area, his call will automatically be routed to an operator.

Panel Type Selecting Mechanism. An important mechanism of a machine switching system is the selector and its associated multiple bank. It is a device by means of which trunks or lines are connected together as required. It performs the same function as the switchboard cord and plug which in a manual exchange can be plugged by the operator into any one of a number of jacks which are the terminals of trunks or lines.

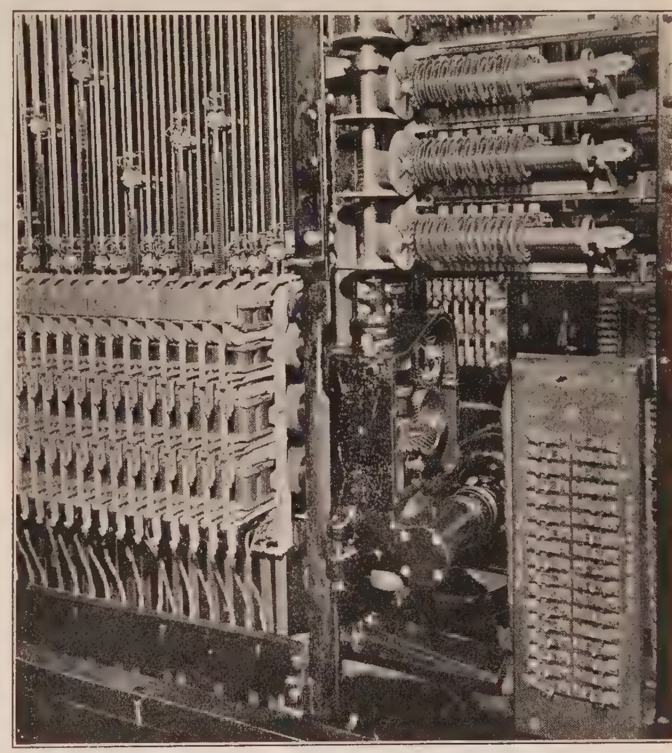


Fig. 9—View of the Selector

Fig. 9 shows the mechanical elements of the selectors. The movable member corresponds to the cord and plug of the manual system and the fixed terminals or multiple, to which the movable member can make connection, corresponds to the jacks of the manual system.

Fig. 10 shows the fixed terminals or multiple to which the selectors connect. This multiple consists of flat punchings about 3½ feet long and 1 inch wide overall. Each of these strips has lugs on each side with which the selectors can make contact. In this particular panel, three hundred of these strips are piled one above the other, separated by insulation, and securely bolted together, forming a panel about 15 inches high.

This panel provides a multiple consisting of "tip," "ring" and "sleeve" connection for one hundred lines appearing sixty times; that is, thirty on each side. The insulating material consists of special impregnated paper and is of such a nature that, after the panel is assembled and baked, it becomes inert and is not ad-

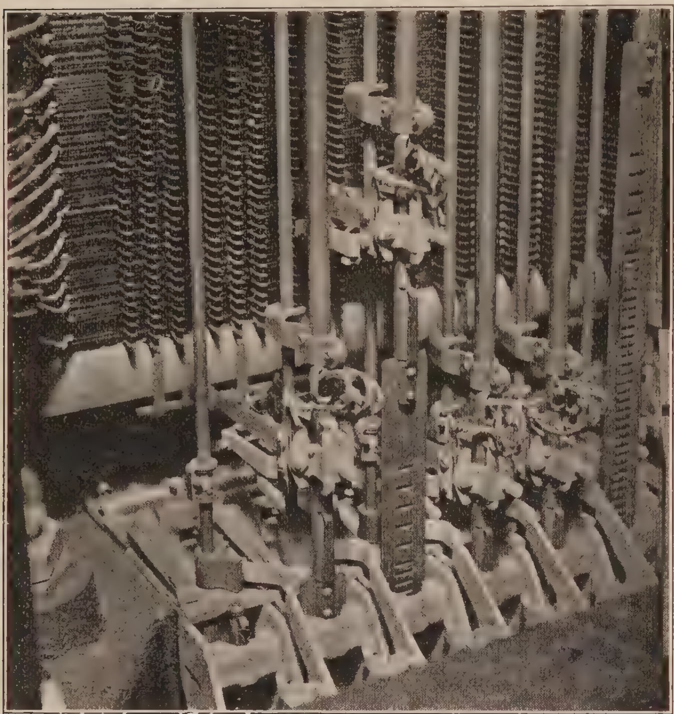


Fig. 9a—View of the Selector

versely affected by any conditions met with in a central office. It is this panel which has given the name to the system.

As shown in Fig. 9, the selector consists of a metal

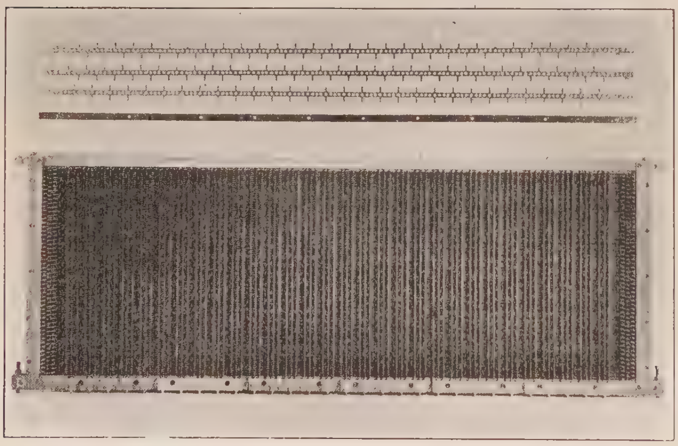


Fig. 10—Selector Multiple Bank

tube supported in bearings allowing vertical motion and carrying five sets of brushes. Each one of the five sets of brushes is arranged to make connections to the tip, ring and sleeve terminals of the panel banks before which it normally stands, and the tip, ring and sleeve contact members of all five of these brushes are multiplied together. They are normally free from contact with the terminals, but any set may be tripped mechanically, so that that set will contact successively over terminals as the selector rises.

A friction clutch is provided at the base of each selector, so arranged that the selector can be raised or lowered by power supplied by a constantly rotating small motor, common to 60 selectors. A magnet is also provided for tripping, by means of a rotating rod, any one of the five sets of brushes into mechanical engagement with the terminals. In choosing a trunk or line, that one of the five sets of brushes which has access to the panel in which the desired trunk or line happens to be, is tripped so that it makes contact with the bank

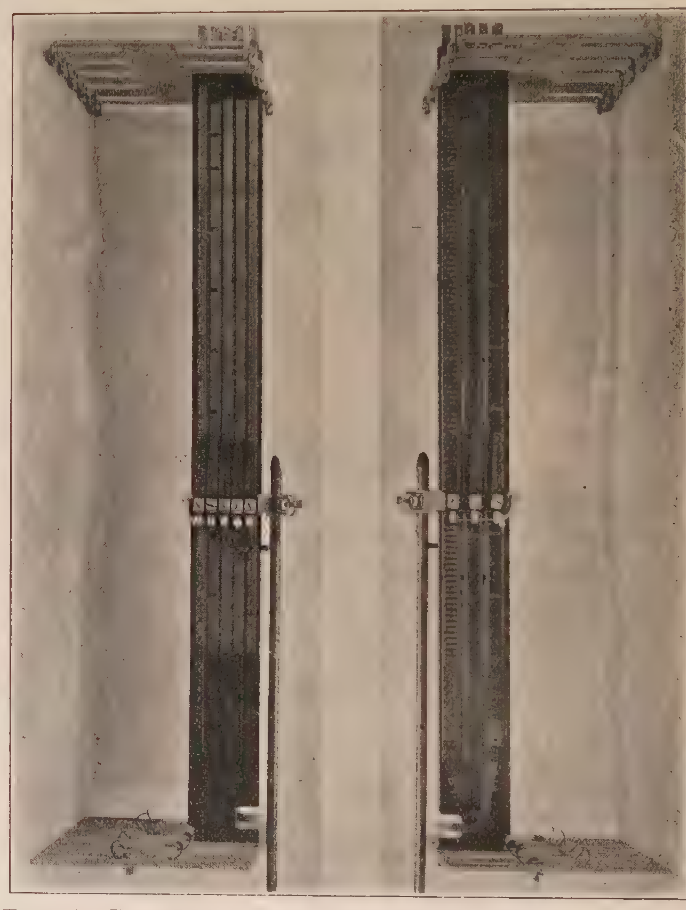


Fig. 11—Commutator for Controlling Vertical Movement of Selecting Mechanism

terminals before it. The selector then moves upward, under the proper control, until the tripped brush engages the desired line or trunk. The selector is then held in this position by a pawl associated with the clutch. When the connection is to be taken down, the pawl is withdrawn, and the selector is carried back by means of the power drive controlled by the clutch. When the selector reaches its normal position the tripped brush is reset.

Selectors used for different purposes are arranged to move their brushes upward at different speeds. The speed most commonly employed moves the brushes over the terminals at the rate of 60 trunks per second. At

the top of the frame, just above the fifth bank, are located commutators as shown in Fig. 11, one for each selector. The multiple wiring of the brushes on the selector leads to other brushes which move over strips on these commutators, and thereby completes the connection from the movable selector to the rest of the circuit, thus avoiding flexible wire connections with

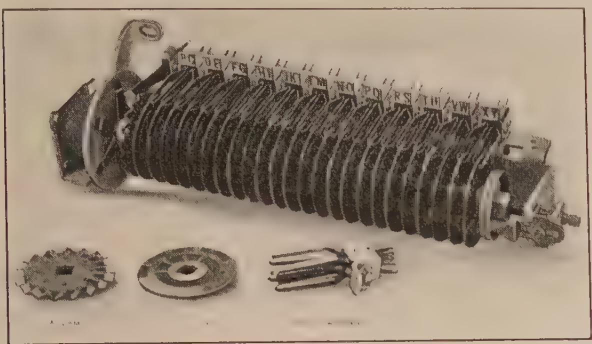


Fig. 12—Sequence Switch Assembly

their attendant troubles. This commutator, also, performs the more important service of controlling the travel of the selector. Brushes moving over conducting segments separated by insulation produce impulses

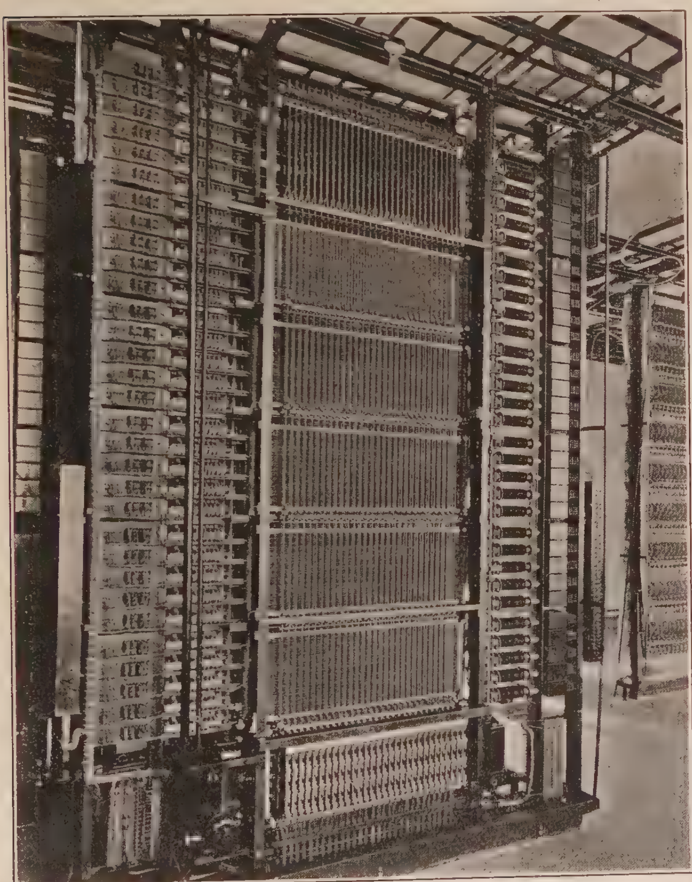


Fig. 13—Selector Frame Completely Equipped

which, when sent back to the sender, indicate to it the exact position of the selecting mechanism.

Sequence Switch. Another device of great importance is the "sequence switch," shown in detail in Fig. 12. It is operated through an electromagnetic switch from the same motor that drives the selectors.

The sequence switch may be described as a circuit controller or device whose function is to establish in a definite sequence such circuit conditions as are required in the operation of the system. It is made up of circular disks called cams mounted rigidly on a shaft. The plates of the cams are cut so that brushes come in

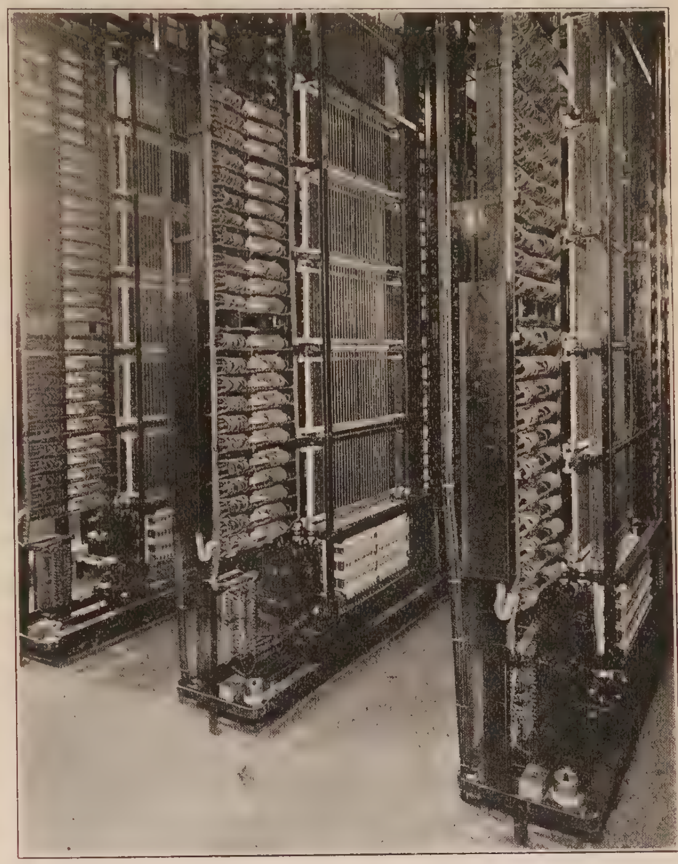


Fig. 14—Group of Typical Selector Frames

contact with the plates only when the circuit is to be closed. The sequence switch can be stopped at any one of eighteen different positions as required, by the simple opening of the electromagnetic clutch.

There are many of these sequence switches used in this system, and the arrangement of cutting the cams varies, depending upon the particular circuit combinations which it is desired to establish.

Selector Frames. Fig. 13 shows thirty selectors with all of the associated mechanism mounted upon one side of a frame ready for operation in an exchange. Both sides of the frame are alike. Five panels of 100 lines each are mounted in this frame, one above the other, giving a total capacity of 500 trunks or lines. Thirty selectors, each capable of making connection with any one of the 500 trunks or lines, are placed adjacent to each other on each side of these panels; the entire frame thereby having a capacity of sixty selectors, each of which has access to 500 trunks or lines.

Immediately to the right of the selectors are the sequence switches and, under protective covers, such relays as are used in connection with the selectors upon the frame shown.

Selecting apparatus of this general type, but differing in details of design, is used during the different stages of the call as line finders, district selectors, incoming selectors and final selectors, reference to which has been made before. Fig. 14 shows a section of a machine switching office with some of the typical frames.

The use of apparatus of the substantial construction just described is made possible only through the use of the sender which receives impulses from the subscriber at the rate they are dialed and receives impulses from the selecting mechanism at the rate it is traveling. This obviates the necessity for restrictions in the design of either the dialing circuit or the selecting circuit, such as would be necessary if they were tied together.

Power Supply Arrangements. Since most of the operations normally required in handling a call in a machine switching office are carried out mechanically, it is evident that a considerably larger amount of power is required than with the manual system. Selectors and sequence switches are propelled mechanically by rotating

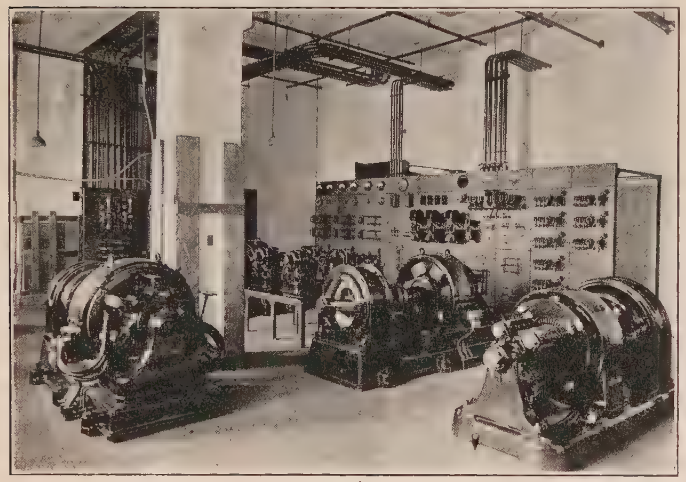


Fig. 15—Power Machine and Control Equipment for Two 10,000-Line Units

shafts driven continuously by small motors mounted on each frame.

The use of small motors on each frame gives a flexible and reliable source of power particularly since the motors now being used are of the special "duplex" type developed for the purpose. They consist of two motor elements in one frame, one element being normally driven from the commercial power service and the other being driven by the telephone reserve storage battery to which it is automatically connected by a relay inside the motor when the regular power fails. A power failure, therefore, causes no interruption to the drive. The selectors are arranged so that not more than half in any one group are driven by the same motor which insures continuous service in case of motor failure.

The main power requirement is for direct current at about 24 and 48 volts which is furnished from motor generator sets (Fig. 15) of special construction to reduce noise, converting the commerical alternating or direct power current into current which is regulated as to voltage and is free from variations which would cause noise in the telephone circuits.

Storage batteries (Fig. 16) floating across the current supply bus-bars insure regulation. In addition to stabilizing the voltage and reducing noise interference from the machines and between telephone circuits, the

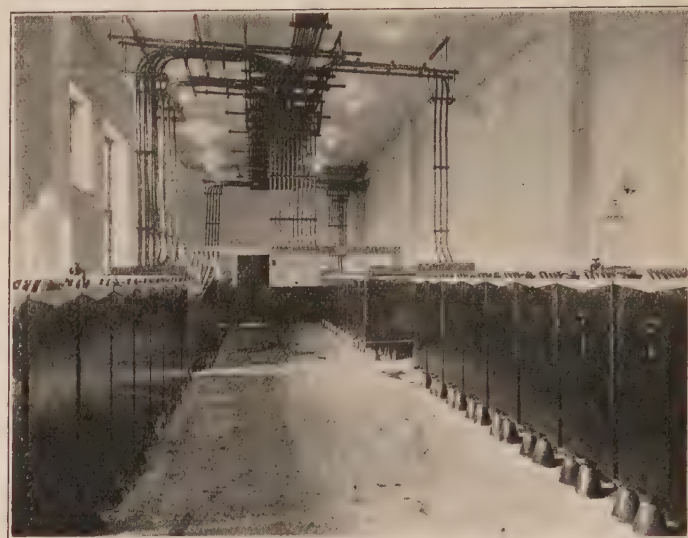


Fig. 16—Battery Room for Two 10,000-Line Units

batteries perform the important function of keeping the exchange in operation during interruptions to the commercial power service. Small motor generators furnish current for ringing subscribers' bells and drive commutators supplying various tones and signals. Batteries or machines supply current for operating coin boxes and

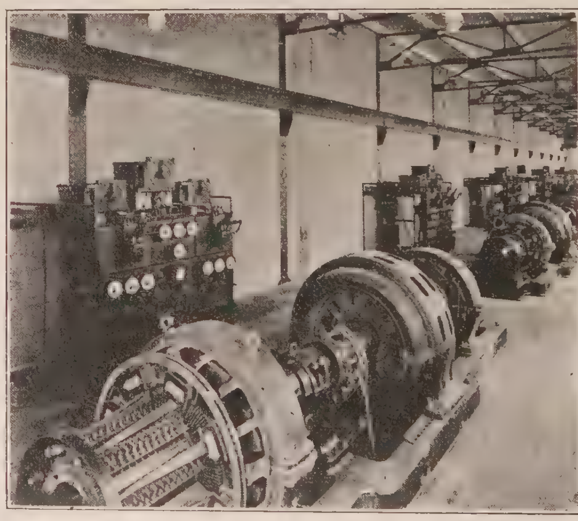


Fig. 17—165 h. p. Gas Engine Generating Set for Emergency Use

pulse machines provide impulses for the operation of certain of the machine switching apparatus.

Whenever practicable, two or more commercial power services from independent generating stations are secured, either of which will keep the office supplied. Where independent generating systems are not available a reserve gas engine supply (Fig. 17) is installed to take the place of the incoming power service, such engine

also being equipped for emergency operation on gasoline.

All of the essential power machines and batteries are provided in duplicate and as indicated, are arranged to come into action automatically wherever this is necessary to insure continuity of service in the event of loss of power or trouble with any of the power equipment. Alarms are provided to detect variations in battery voltage, blowing of fuses, stopping of machines or any failure of service on all power busses which feed energy to the telephone or signaling circuits. The power plant is thus designed to give an uninterrupted energy supply at all times even when the usual sources of power may have been temporarily discontinued.

Detailed Plan of Operation

The following will give in some detail the plan of operation for handling typical calls between various types of offices in a large metropolitan area such as New York City.

Calls Originating in Machine Switching Offices. Fig. 18 shows schematically the path of a call originating in a machine switching office. The pair of wires of a subscriber's line is attached to one of the sets of fixed terminals in a panel bank appearing before a group of selectors of the type which has been described. By putting fewer lines in these panels and increasing the number of selector brushes, we attain the speed neces-

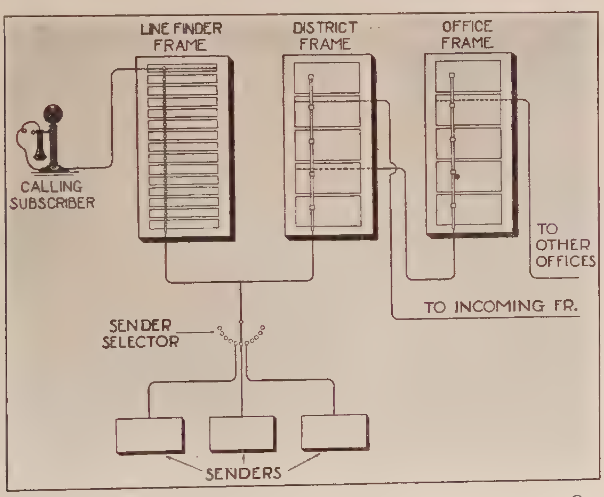


Fig. 18—Diagram of Line Finder, District and Office Frames

sary at this stage of the connection. These selectors are called "line finders," since their function is to find calling lines. The terminals correspond to the answering jacks and the selectors to the "A" operators' answering cords of the manual system.

When the subscriber removes his receiver, he closes the circuit of his line, causing a relay at the central office in series with his line, to operate. This relay causes an idle line finder, having access to his line, to trip the proper brush and then move upward to his line. At the same time a sender selector attached to that line finder is choosing, out of a common group, an idle sender. The sender selector is a small selector of a type in which the brushes are driven by a magnet over contacts arranged as shown in Fig. 19.

The sender having been attached in this manner to the calling line, a low humming sound, known as the dial tone, is heard by the subscriber, advising him that the mechanism is ready for him to dial. The entire sequence of events just described takes place in a fraction of a second, so that ordinarily the subscriber finds the dial tone when the receiver reaches his ear.

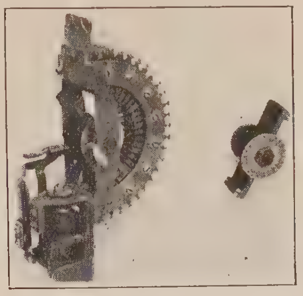


Fig. 19—Sender Selector

The subscriber now dials the required letters of the office name, and the numerals of the called number.

The pulses from the dial come over the subscriber's line through the line finder and sender selector to the sender which records and translates them to control the setting up of the connection. As soon as the connection has been established, the sender is released and is ready to be used for a new call, being kept in use only a few seconds for each call.

The first step in completing the connection is to choose an idle trunk in the proper direction. To the nearby offices there are groups of direct trunks, whereas the more distant offices are reached through tandem centers described later.

The line finder leads to the movable element of a panel selector known as a "district selector." This district selector has capacity for 450 working outgoing trunks, the other 50 trunks being used for control purposes. In a small city 450 trunks would be sufficient to reach all points, but in the case of the New York offices 450 outgoing trunks are not sufficient. Accordingly, only a few of the trunk groups outgoing from these offices leave directly from the district selectors. To obtain access to the remaining trunks there are, on every district selector frame, groups of trunks leading to so-called "office selectors." These office selectors are of the panel type and each has a capacity for 450 outgoing trunks.

The path of a call through a district and office selector will now be traced. The district selector starts upward under the control of the sender. As the district selector moves upward, it produces pulses by means of the brushes which slide over the commutator at the top of the selector. These pulses are transmitted back to the sender, and are there counted. When the sender has counted the number of pulses which indicates

to it that the district selector has proceeded to the proper position, the sender opens the fundamental circuit to the selector and causes it to stop. This method of controlling the movement of the selector is termed the reverse control method.

The first selection made chooses the set of brushes to be tripped into engagement with the terminals. Assume, as shown in Fig. 18, the desired trunk appears on the second panel from the bottom. Therefore, the district selector is allowed to make two pulses and is then stopped by the sender. The brush-tripping device is thus set in position to trip the second brush, and the selector is started again by a signal from the sender, which operation completes the process of tripping the brush.

The selector now continues upward, making a pulse for every group of trunks which it passes over, until, having reached the desired group, as indicated by the number of pulses counted by the sender, it is again stopped by the sender at the beginning of this group. The selector is now started again, and this time under its own control, hunts for an idle trunk in the group. Busy trunks are grounded on the third or signaling terminals, whereas idle trunks are open. A testing relay, associated with the selector, keeps the selector moving upward until a trunk with an open third wire is found, whereupon the selector stops, makes connection with this trunk, and renders it busy to other selectors by grounding the signaling strip.

This trunk, as indicated in Fig. 18, leads to an office selector. The same process is repeated by the office selector, under control of the sender, to trip first the proper brush, then choose the proper group, and finally to choose an idle trunk in the group. The connection is now extended to an outgoing trunk. The sender still remains attached to the connection, since it must still control the further setting up of the connection.

The sizes of the working trunk groups on district and office selectors can vary from 5 to 90, depending upon the traffic to be handled.

Calls Between Machine Switching Offices. If the call is for a subscriber in a machine switching office it is completed as shown in Fig. 20. This figure shows a diagram of the apparatus used to connect an incoming full mechanical trunk to a subscriber's line, whether this line is in the originating machine switching office or in another which must be reached over interoffice trunks.

The incoming trunk to the machine switching office terminates on an "incoming selector," which is of the type already described. The machine switching office has a capacity for 10,000 numbers, but the incoming selector has capacity of only 500 trunks, so that the same arrangement is employed as on the district selectors; that is, the incoming selector chooses one of a number of other selectors, called "final selectors," which have access to the subscribers' lines. Since each group of final selectors has access to 500 subscribers, 20 groups of finals will be necessary to care for the full 10,000 numbers. On the incoming selector frames, therefore, appear 20 groups of trunks, each group leading to a different frame of final selectors.

The method of selection is the same as described for the district and office selectors; that is, first the incoming selector, under control of the sender in the originating office, trips the proper brush, chooses the proper group, and finally chooses an idle trunk leading to a final selector. The final selector then goes through the process of brush, group, and subscriber's terminal selection. The terminal selection is under the control of the sender which counts line by line in the group of ten, until the desired one is reached. If the called line is idle, it is rung, and the calling subscriber is advised of that fact by hearing the audible ringing signal. If the called line is busy it is not connected, but an intermittent buzz, recognized as the busy signal, is sent back to the calling subscriber. If the called number is that of a P. B. X. having several trunks, the final selector automatically hunts for an idle one. If the

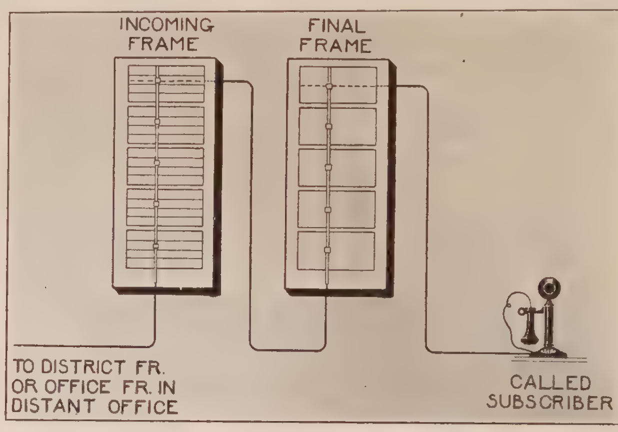


Fig. 20—Diagram of Incoming and Final Frames

final selector, after testing all the P. B. X. trunks finds them all busy, it sends back the busy signal.

As soon as the called line is reached, the sender is dropped from the circuit to be available for another connection. It is not held during the period of ringing, during the time that the busy signal is being given, if the line is busy, or during any part of the period of conversation.

It will be noted that the method of selection is not on a decimal basis. The first selection is to choose one of five brushes on the incoming selector as already explained; that is, we choose that particular fifth of the terminals in which the called line happens to be, and since 1/5 of 10,000 is 2000, we choose the 2000 group desired. The next selection is by groups of 500, which is again non-decimal. This "translation," as it is called, of the number from the decimal notation, as dialed by the subscriber, into the notation as needed by the selectors, is taken care of very simply in the senders.

Calls from Machine Switching to Manual Offices. Calls from machine switching to manual offices are handled at the manual office on call indicator "B" positions. Fig. 21 shows a diagram of the equipment used to connect such a call to a subscriber in the manual office.

The call progresses through the district and office selector in the same manner as described for the machine switching call, but the trunk which it takes up leads to

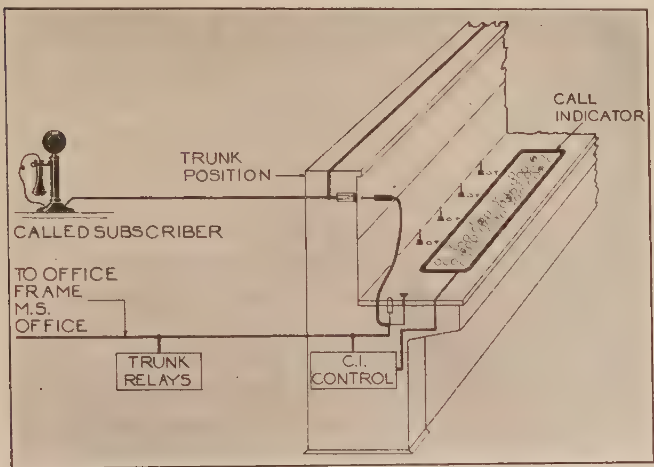


Fig. 21—Diagram of Connection from Machine Switching to Manual

a call indicator "B" position in the manual office selected. The operator is notified that a call has reached her position by the lighting of a lamp associated with the cord and plug in which the incoming trunk terminates. Upon perceiving this signal, she presses a display key associated with that trunk, and thereupon

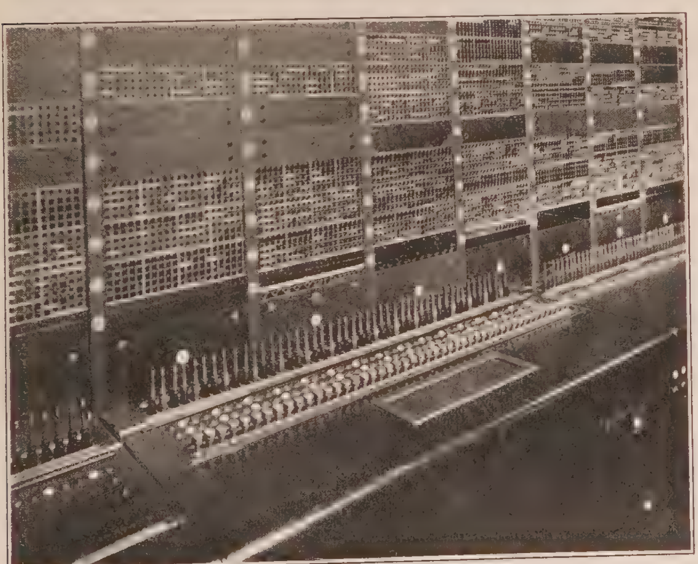


Fig. 22—Incoming Trunk Position in a Manual Office Arranged for Call Indicator Operation

the called subscriber's number is displayed on a bank of numbered lamps located on this operator's keyboard. The operator picks up the plug, tests the called line and, if it is found idle, plugs in; or, if it is found busy, she plugs into a special jack which is arranged to send the intermittent busy tone back to the calling subscriber.

The called subscriber's number is displayed in the following manner. Associated with the operator's position, and with her call indicator, is a group of relays. When the display key is depressed, this group of relays is attached to the trunk. The sender which has meanwhile been waiting on the connection, is thereby given a signal, and sends the number called by means of code pulses which are received by the group of relays. These relays, in turn, light the set of lamps on the call indicator corresponding to the digits of the called number, as shown in Figs. 22 and 23. The code

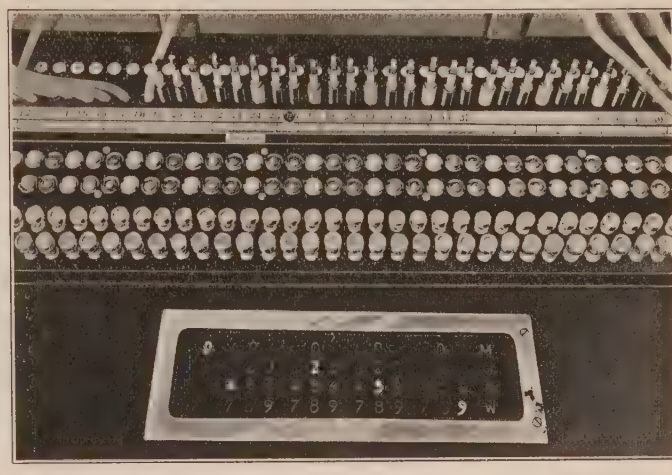


Fig. 23—Call Indicator at an Incoming Trunk Position in a Manual Office

pulses employed for sending this called number are positive and negative, strong and weak, and are translated by the sender from the decimal dial pulses to this type of pulse to reduce the time required and to simplify the receiving apparatus.

Incoming Calls from Manual to Machine Switching Offices. Calls from manual offices are handled at the machine switching office on the cordless "B" positions.

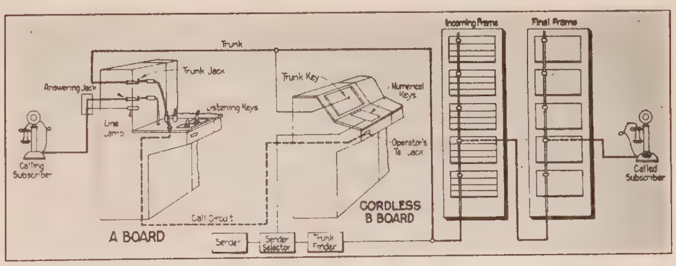


Fig. 24—Diagram of a Connection from a Manual to a Machine Switching Office

Fig. 24 shows a diagram of the equipment used to connect a call originating in a manual office destined for a subscriber in a machine switching office. Such a call is answered by the "A" operator in the manual office in the usual manner. She takes up the call circuit by depressing her call circuit key to the machine switching office desired, passes the called subscriber's number, and receives a trunk assignment in exactly the same manner as if the call were going to another manual office. The

cordless "B" operator, upon assigning a trunk, presses the assignment key of that trunk, which temporarily attaches her keyboard to a sender and simultaneously to the incoming trunk which she has assigned. As shown in Fig. 24, the incoming trunk terminates on an incoming selector which has access to final selectors on which the called number appears, in the same manner as described before.

The operator now sets up on her numbered keys the number desired, and this information is transmitted immediately to the sender. These keys, which lock mechanically, are released after a fraction of a second

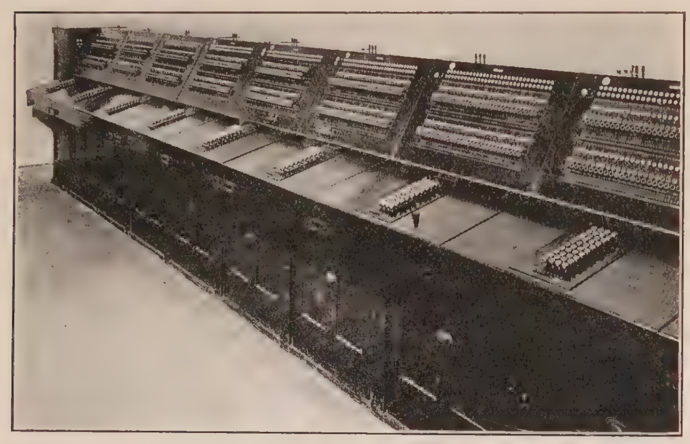


Fig. 25—Cordless "B" Positions in Machine Switching Office

by a magnet controlled by the sender and are ready for the next call. The "B" operator's sender now controls the incoming and final selectors in the same manner as the subscribers' senders, causing the incoming selector to choose an idle trunk to a final selector having access to the desired group of 500 numbers. The final selector reaches its destination in the manner previously described and, as soon as the line is found, the sender is released.

Fig. 25 shows a line of cordless positions. The section at the left is the cable turning section, having nothing to do with the operation of the board.

Manual Positions Required in Machine Switching Offices. While regular calls between two subscribers will be completed in this system without the aid of operators, certain classes of calls, such as toll calls to suburban points and calls for discontinued or changed numbers, etc., will require the assistance of an operator. Special manual positions are therefore provided in the machine switching office for this service. These positions also care for cases where the subscriber may need the assistance of an operator for other reasons than the above, and are in addition to the cordless "B" positions previously described.

The operators are called "Special Service Operators." The subscriber signals them by dialing "Zero," which on the dial is also marked with the word "Operator." The connection then progresses in the same general manner, through the district and office selectors, as for any originating call. An idle trunk appearing on the office selector leading to an answering jack before the special service operator is chosen and the sender released. Should a subscriber in any local service area dial a subscriber in another area, the sender will automatically route the call to a special service operator.

The special service operator in large areas has before her a number of cord circuits having one end terminating in a cord and plug. She also has upon a keyboard a set of keys similar to those described for the cordless "B" position, except that there are additional strips of keys upon which she can write up an office code. The operator answers the subscriber by inserting one of the plugs in the answering jack and, having ascertained the desires of the subscriber, directs the connection to the proper destination by setting up on her keys the proper numerical code. Senders are furnished for these positions so that, as soon as the information from the keyboard has been registered on the sender, the keys are released and are ready for another call.

The other end of the special service operator's cord circuit terminates in a district selector which, either directly or through other selectors, has access not only to trunks which the subscriber himself might call, but also to trunks leading to more distant offices which he cannot dial directly because they are toll points.

Tandem Operation. There are about 158 central offices in the area shown on the map, Fig. 3. While it is an essential requirement that any subscriber connected to any of these offices be able to reach any subscriber connected to any other office, it is obvious that to furnish trunks from each office direct to every other office would require a great number of long trunks in small groups carrying a very light load most of the time.

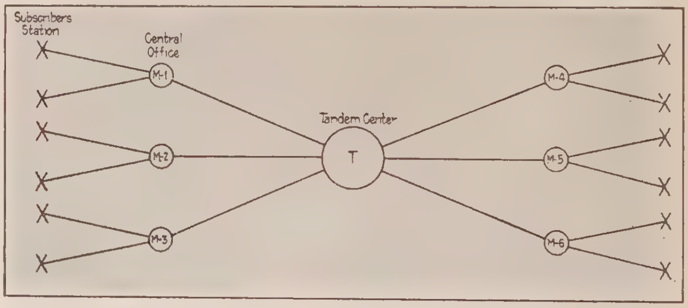


Fig. 26—Typical Tandem Trunking Plan

In order to eliminate the inefficiency that such an arrangement would entail, it has been the practise in manual operation to handle the traffic from one part of the area to another part of the area over main trunk routes. The collecting and distributing points on these trunk routes are known as "tandem centers," and the plan of operation is known as "tandem operation."

Fig. 26 shows an arrangement of offices in a typical tandem trunking plan. Offices marked M are local offices, either manual or machine switching. The office marked T is a tandem office. If a call is originated by a subscriber in office M-1 for a subscriber in offices

M-4, M-5, or M-6, to which no direct trunks are provided, the call is routed at office M-1 to trunks terminating at tandem office T. At this point they are connected to trunks leading to the proper office, where the connection is completed to the desired subscriber in the usual manner. Likewise, calls from offices M-2 and M-3 are completed over the same groups of trunks rom the tandem office T to offices M-4, M-5, or M-6.

The plan described above is typical of that followed in the New York Metropolitan area for many years, the completion of the call being controlled at the tandem office by operators.

The machine switching system is not only adapted to fit into the existing tandem plan, either when used in the local central office or at the tandem office, but also makes available possibilities for considerably extending the field of usefulness of the tandem system, due to certain advantages in handling calls at tandem points by the use of machinery.

The use of a sender at the machine switching office which is capable of routing a call in any way desired permits locating the selectors which have access to the interoffice trunks at any convenient point either at the

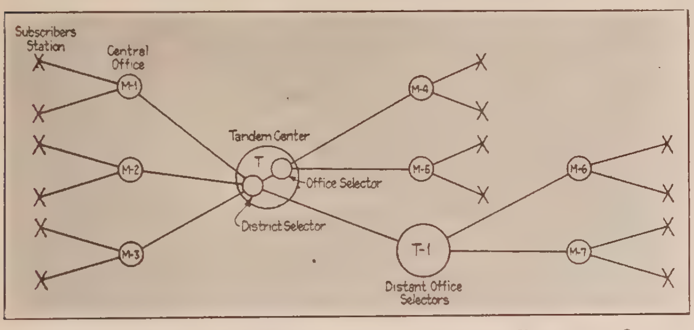


Fig. 27—Tandem Trunking Plan Showing Distant Office Selector

originating office or at some distant point. In other words, the tandem office T shown on Fig. 26 may consist of a group of office selectors such as have been described previously. In this case the trunks from offices M-1, M-2 and M-3 would lead from district selectors in these offices to the office selectors at office T which would select, under control of the sender in the originating office, an idle trunk to office M-4, M-5, or M-6, as desired. At the terminating office the call would be completed through incoming and finals if it is a machine switching office, or call indicator "B" positions if it is a manual office, exactly as described previously.

If the number of points to be reached through the tandem office is greater than the capacity of a group of office selectors, a group of district selectors may be provided at the tandem office which have access to groups of office selectors located at the same office or at some distant point, as described above.

Fig. 27 shows schematically a tandem plan using the above method. Tandem office T is provided with district selectors on which terminate trunks from local offices M-1, M-2 and M-3. These selectors have access to office selectors in the same office through which offices M-4 and M-5 are reached, and to office selectors located in the distant tandem office T-1 through which offices M-6 and M-7 are reached.

To handle calls at a machine switching tandem office originating from manual offices, operators are required at the tandem office. These operators handle calls in much the same manner as cordless "B" operators in a machine switching office, as already described. The operator receives the desired office name and number from the originating operator over a call circuit and sets it up on her keyboard, which is similar to the cordless "B" board, except that it has office keys in addition to the numerical keys. The number is received by a sender which then controls the operation of the selecting mechanism in the tandem office and other offices through which the call may pass, to the desired local office and subscriber's line.

Many different combinations of the above are possible and are employed when desired.

Maintenance

As will have become apparent from the description already given there is, in the machine switching telephone central office, a large amount of apparatus which, in order to insure service of good quality, must be maintained in proper working condition. Consequently, the subject of maintenance has been very carefully kept in mind throughout the design of the system. For instance, all new pieces of apparatus used in this system have been subjected to the most rigid tests to insure that they will have a satisfactory life and that their margins of adjustment will be adequate.

When maintaining machine switching equipment, the main reliance is placed on preventive measures, so that incipient faults will be detected and corrected before they have got to the point of interfering with service. Ingenious automatic testing arrangements have been designed to aid in this preventive maintenance work. They subject the various circuits in the exchange to routine tests, and are arranged so that they will automatically test all of the circuits, one by one, under conditions more severe than they will ever be called upon to meet in service. In case some feature of any circuit has deteriorated from its normal standard of adjustment—which includes a wide margin—so that it will not meet this severe testing condition, the testing apparatus automatically stops and by supervisory lamps indicate the location of the trouble. An audible alarm is also sounded which notifies the maintenance man responsible that something requiring his attention has been found. The circuit in trouble may still be capable of giving service, but is below the standard set and may soon give service trouble if not corrected.

As applied to the sender, for example,the automatic routine test equipment picks up each sender in turn and puts it through its regular process of operation, under

conditions more severe than are encountered in practise. If the sender under test meets the operating conditions without failure, the sender is dropped and the test equipment moves to the next sender. If any trouble develops an alarm is given, which summons the maintenance man who is able to determine by the condition of the apparatus the location of potential trouble.

The operation of the testing equipment may be varied by suitable keys, so that all the features of each sender may be tested once, or so that any one feature of the sender may be tested as many times as desired.

All the equipment in the office occurs in groups, and arrangements are made for readily taking out of service for readjustment any piece of apparatus which may have been found to have potential trouble—the other members of the group continuing to handle the calls.

Application

In the preceding pages there has been briefly described a switching system which meets the exacting and complex requirements of telephone service in the largest cities and in which, so far as is practicable, the various switching operations are performed automatically. Only such operators are required in connection with this system as are necessary for handling special classes of service and certain operations in connection with the interchange of calls between manual and machine switching central offices during the transition period.

Variations in the arrangements which have been described have been developed and are available for use whenever the conditions warrant. An illustration of this is the so-called key indicator, which permits the handling of calls from manual to machine switching offices without the aid of the cordless "B" operators. This is effected by providing the operators in the manual offices with special keys and equipment for controlling directly the selection of the subscriber's line in the machine switching office.

This machine switching system marks a very important advance in a development which began shortly after the telephone was invented, and which has been most vigorously prosecuted by the engineers of the Bell System from then to the present time. Throughout this entire development period the tendency has been to introduce automatic methods and apparatus whenever they gave a better result to the public, or whenever they were attended by an economy of any kind.

How this system works has been briefly explained. What arrangements are provided for handling regular machine switching calls, calls to and from existing manual offices, private branch exchanges, etc., has been described. How the introduction of this system into a telephone network is affected will now be discussed briefly.

Obviously, the problem of introducing machine switching equipment into such an extensive and complex structure as is the telephone plant of a big city, is a large one. It is impracticable to introduce it all at once. Its introduction must be effected gradually and this is accomplished by using it for growth and such replacements as are necessary, later extending its use as conditions warrant.

The fundamental engineering studies which have to be made and which must precede the manufacture and installation of the equipment for a machine switching office are, in all important respects, the same as those which must precede the manufacture and installation of the equipment in a new manual office. They involve a careful study of the telephone needs of the area, with a view to determining ultimately the quantities of the different kinds of arrangements necessary to give the service. This requires a study of the commercial requirements at the time when the equipment should be cut over and for several years thereafter. Data must be collected as to the probable rates of calling, the average duration of the calls and the amount of trunking to and from other offices.

With these data available, the size and arrangement of the trunk groups on the selector frames, the number, grouping and type of selectors and senders required, and the size of the power plant can be determined. From this the cabling arrangement can be worked out, and suitable floor plans prepared.

Manufacturing specifications can then be prepared in accordance with which the equipment of the office is manufactured and installed. Before the equipment is cut into service, the various arrangements are thoroughly tested individually, and when in proper condition the whole is checked up by making complete operation tests.

If time and space permitted, it would be of interest to discuss the methods of actually cutting the equipment into service, and the comprehensive program which is worked out for the training of the employees who are to handle the equipment and advising the public which is to use it. All these matters are of the utmost importance, and must be carried out systematically in order that there may be no reactions on the general service at the time of the cut-over.

LIGHT SUPPRESSES CRIME

Lights in dark parts of certain cities would do more to suppress crime than three times the present number of policemen, declared Prof. William J. Drisko at M. I. T. More than 600 persons attended his lecture on "Illuminants and Illumination," in the popular science series given by the Society of Arts.

Better lighting, furthermore, stimulates clean habits of living, he said, eliminates imperfect sanitary conditions, cuts down the number of accidents in industry and everyday life and increases industrial production in both quantity and quality. He pointed out that proper lighting has a great economic value in keeping men at skilled occupations for a longer period, due to lesser eye strain, than prevails under improper conditions.

Some Fuel Determinations Made on Locomotives Operated by the Southern Pacific System

BY A. H. BABCOCK
Fellow, A. I. E. E.
Electrical Engineer, Southern Pacific Railroad, San Francisco, Cal.

WHENEVER electrification of steam railways on a large scale is advocated, one of the principal arguments advanced is the large saving in fuel sure to result therefrom; in fact, this was the initial point of attack in the early days of the art—the early 1890's, for example—long before overtime of train and engine crews had become the very real expense in train operation it is today. Many attempts to get accurate information on locomotive fuel consumption have been made during the intervening years, for comparison with known electric locomotive performance.

Fuel consumptions of steam locomotives using coal cannot be analyzed as can those of electric locomotives, because it is impossible to obtain accurate measurements. When fuel oil is used, the possible accuracy of such measurements more nearly approaches that of electric operation, and much more precise determinations are possible.

By the use of accurately calibrated oil meters; by locating with reference to track conditions, points at which meter readings shall be taken; by choosing an engine that has shown an average fuel performance under widely different operating conditions; by giving this engine loads as closely as possible to its rating; and by not changing the train consist over the run, an accurate measure of fuel consumption for any given piece of track—over a mountain, for example—can be had.

In connection with and bearing directly upon electrification possibilities, such a study has been made of the track over the Tehachapi Pass, where topographical and operating conditions are severe; also they are representative of Mountain Railways on the West Coast.[1]

Engine No. 3614 was selected because the records of the Fuel Bureau showed it to be an "average performer" in through freight service. Its characteristics are given in detail, Figs. 1 and 2. On every run a different engine crew handled the train, the selection being by the usual "first in, first out" method standard on the railway. A trained observer rode the engine and made all the readings. The train weights, taken from the yardmaster's reports at the initial points, were corrected, during the runs, for fuel and water consumed.

Mr. Geo. McCormick, General Superintendent Motive Power, Southern Pacific Lines, afforded every facility of his department in the prosecution of the work; he prepared the engine and made valuable suggestions.

The division officials inconvenienced themselves many times to permit a single engine train to run without change of load over a congested piece of track.

Mr. William Hood, for many years Chief Engineer, Southern Pacific Co., who located and constructed this line, named the points at which the track conditions change in significant fashion. It was found during the test runs that all engineers handled the trains very

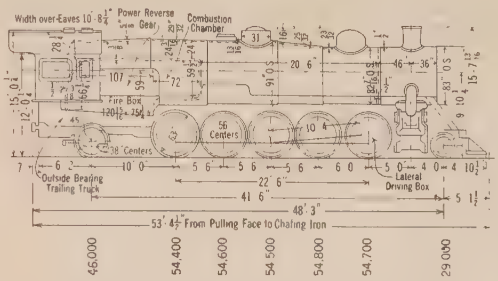


FIG. 1 —SPECIFICATIONS

Cylinders	27½ in. x 32 in. Stroke
Weight on drivers	273,000 lb.
Weight on front truck	29,000 lb.
Weight on trailing truck	46,000 lb.
Weight of engine loaded	348,000 lb.
Driving axle journals, front	10 in. x 20 in.
Driving axle journals, main	12 in. x 22 in.
Driving axle journals, others	10 in. x 13 in.
Trailing truck, journals	8 in. x 14 in.
Engine truck journals	6 in. x 12 in.
Boiler tubes, diam. of	2 in. and 5⅜ in.
Boiler tubes, length of	20 ft. 6 in.
Boiler tubes, number of 2-in	279
Boiler tubes, number of 5⅜ in	40
Heating surface of boiler tubes	4130 sq. ft.
Heating surface of super heater	972 sq. ft.
Equiv. H. S. of superheater	1458 sq. ft.
Heating surface of firebox	327 sq. ft.
Equiv. heating surface, total	5915 sq. ft.
Fire box, length inside	120-15/16 in.
Fire box, width inside	75¼ in.
Water space sides, back and front	5 in.
Grate area	63 sq. ft.
Boiler pressure	200 lb.
Equiv. heating surf. to cyl. vol	269
Adhesive wt. to equiv. H. S	46.2
Tractive effort to adhesive wt	0.2392
Adhesive wt. to tractive effort	4.18
Adhesive wt. to total wt	0.785
Tractive effort x diam. of drivers to equiv. heating surface	695.0
Equiv. H. S. to tractive effort	0.0906
Total wt. to equiv. H. S	58.8
Equiv. heat surf. to grate area	93.9
Tractive power (M. E. P. 85 per cent)	63,300

much alike, changing throttle or cutoff at or near the flags that had been placed at the points selected by Mr. Hood; from which it was evident that the points so chosen were really representative. The positions of all these reference points are given in Fig. 3. Meter

1. See also TRANSACTIONS, A. I. E. E., Vol. XXXII, p. 1845, "Mountain Railway Electrification"—*Babcock*.

To be presented at the Spring Convention, Pittsburgh, Pa., April 24-26, 1923.

readings and times were recorded at all grade changes, (marked by these flags, or by the natural marks at such points), and at all starts and stops. The fuel oil was metered through a new two-inch duplex piston type meter that had been calibrated by weight measurements corrected for temperature. In the final analysis

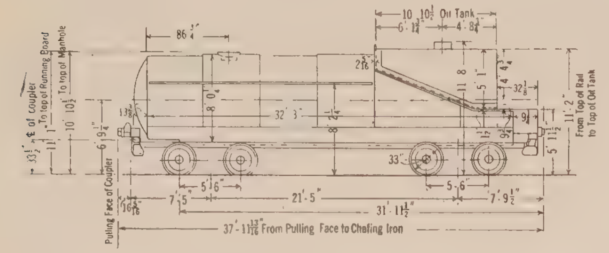


FIG. 2—10,000-GALLON CYLINDRICAL TENDER SPECIFICATIONS

Capacity of fuel oil	3120 gal.
Capacity of water	10,030 gal.
Weight of tender empty	64,900 lb.
Weight of 10,030 gallons of water	83,600 lb.
Weight of 3120 gallons of fuel oil	24,960 lb.
Weight of tender loaded	173,460 lb.
Tender axle journals	6 in. x 11 in.
Weight of truck	8,580 lb.
Height from top of rail to bottom of tank (loaded tender)	2 ft. 9¼ in.
Height from top of rail to center of gravity (loaded tender)	
Width over front steps	9 ft. 6 in.
Width over back steps	10 ft. 2¾ in.
Extreme width over end sills	9 ft. 10 in.
Diameter of tank outside	8 ft. ¼ in.

all fuel measurements were reduced to 60 deg. fahr. Approximate water measurements were made, not to determine evaporation, but as correction factors on the train tonnage. Similar fuel corrections were made.

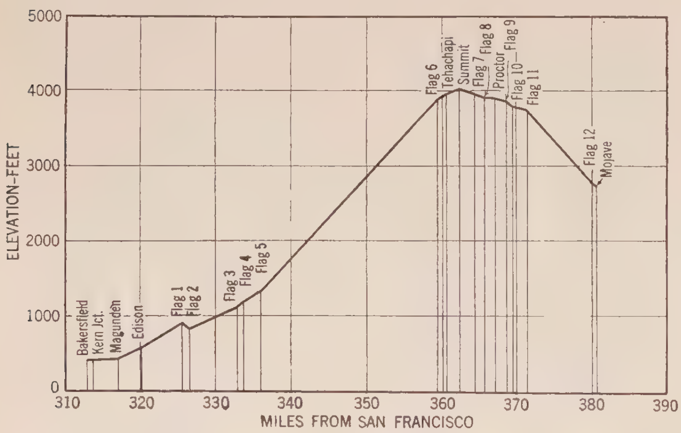


FIG. 3—PROFILE MAP, BAKERSFIELD TO MOJAVE

The train tonnage, then, is gross weight of train from engine pilot to caboose markers, everything included.

The result is a complete record of fuel consumption beginning with the enginehouse firing up and standby fuel consumption until the engine was called; while standing outside the house waiting for the train, testing brakes, during acceleration, running up and down the various grades, holding the train in sidings, and finally running down hill over long stretches of steep grade.

In the ordinary system of fuel records all fuel consumed in firing up, standing in the enginehouse and on the outgoing track up to the time the engineer assumes responsibility, *i. e.*, thirty minutes before he is called to leave the terminal, is charged to enginehouse service; all consumed from that time until the engine is placed on the incoming track at the end of the run is charged to road service.

Such records, brought probably to the highest state of perfection in the practise of the Southern Pacific Co., give merely a method of distribution of charges between departments, provided a basis of comparison between present and past performances quite sufficient for economic operation in pre-war days, but by no means adequate in these days of intensive economic studies. No details of performance are uncovered.

These may be divided into three groups:

1. Variation of fuel used in firing up with respect to feed water temperatures, *i. e.*, losses independent of the manner in which the engine is used after steam is raised.

2. Fuel burned in holding the engine under steam at terminals or on the road; *i. e.*, losses dependent upon operating staff efficiency rather than upon tonnage, and independent of speed.

3. Fuel consumption while moving; accelerating, running, entering and leaving sidings, etc., all of which are dependent largely upon tonnage, and speed. With known tonnage, as in these tests, the ton-mile fuel cost becomes known over widely varying road and running conditions.

Group 1. For this determination the boiler was filled to 1/3 gage glass, (engine in enginehouse), with water at 120 deg. fahr. Steam for oil atomizer and blower was taken from the house steam lines until the boiler pressure reached 70 lb. gage. Fig. 4. shows fuel with respect to boiler water temperature and steam gage pressure. A second curve shows fuel consumption with time. Evidently not all the heat in the fuel reached the water at first because of the cold firebox lining.

From other tests it has been determined that the atomizer and blower add 14 per cent to the fuel consumption. Therefore, if 14 per cent of the 84 gal. used up to the time when the boiler furnished its own steam for these purposes be added to the 119 gal. metered to the burner to bring the boiler pressure up to 200 lb. gage, we have 131 gal., total fuel used to raise steam with feed water at 120 deg. fahr.

If it be assumed, as seems reasonable all things considered, that the fuel consumption for all practical purposes is proportional to the rise in temperature, the fuel per degree rise is 47/(210–120), or 0.522 gal.; from which then can be determined value of storing the heat from boilers being blown down for washing, to use in firing up other engines for the road. Thus, to fire up with feed water at 60 deg., ordinary hydrant water,

costs 1.14 [(0.522 (212 – 60) + (84 – 47)] + (119 – 84) = 167 gal. Similarly for 180 deg. feed water, from a hot water boiler washing and filling plant; 1.14 [0.522 (212 – 180) + (84 – 47)] + (119 – 84) = 96 gal.

With fuel oil at $1.50 per bbl. the 71 gal. saved per engine fired up amounts to $2.54, but the money saved by such procedure is even more than is apparent from the figures, because the time of turning an engine washed and filled with hot water is, by record, 3½ hours less than the 7½ to 8 hours required when cold water is used. Heavy power represents an investment worth at least $4.00 per hour. It could not be rented for this figure. Hence the time saved adds $14.00 per engine turned to the fuel saved, and the total economy then is $16.54 per engine turned.

Group 2. The upward branch of the time-oil curve, Fig. 4, shows the fuel required to hold an engine under steam while standing in the enginehouse where these tests were made, to be 60 (159 – 119) / (246 – 108)

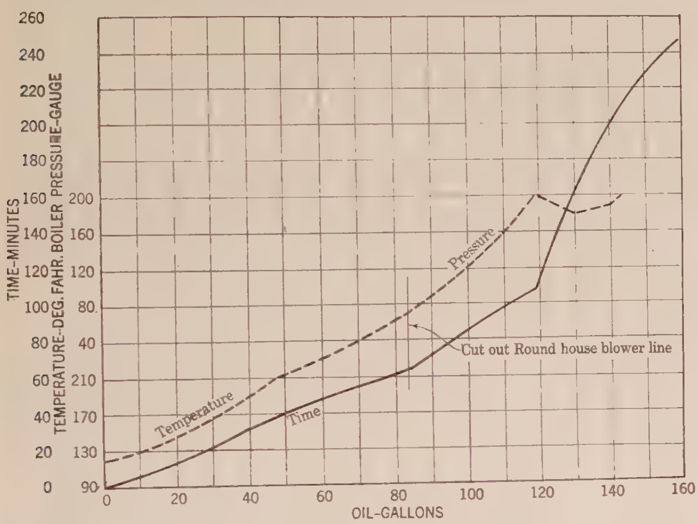


Fig. 4—Fuel and Time Required for Firing Locomotive

= 17.4 gal. per hour. It is fairly representative of large engines standing in a well kept enginehouse, no auxiliaries running.

Power of this class has air reverse gear; hence, if the engine is standing where occasional movements must be made, at least one air pump must be cut in. During the tests it was determined by placing this engine in the open yard, that oil was used at the average rate of 36.6 gal. per hour. Air temperatures during this period ranged, roughly, from 20 deg. to 50 deg. fahr., therefore 36.6 – 17.4 = 19.2 gal. is the excess fuel consumed per engine-hour when standing in the open in ordinary weather.

Similarly, the fuel cost of standing on sidings with full tonnage train, is found to be 42.8 gal. per hour. Since no steam was used for heating in either case, 42.8 – 36.6 = 6.2 gal. is the fuel cost per hour of maintaining air pressure in the train line, ready for service.

Group 3. The results obtained for the first two groups are evident upon even a cursory study of the curves; but to obtain results for the third group a more rigid treatment is necessary. The reduction of the test observations in these determinations occupied many weeks full time of the two observers, (who rode the engine alternately during the tests), Mr. C .M. Barbour and Mr. R. S. Twogood, Assistant Engineers, Southern Pacific Company. Mr. Twogood is responsible for the details of the test and the analysis of the results. To him acknowledgments are due for the following pages, most of which are either taken literally or abstracted freely from his report.

In the reductions of the observations, the fuel oil density is taken at 0.96; the heat content 18,000 B. t. u. per pound. The constants to correct the meter readings for meter error and to reduce to standard temperature, 60 deg. fahr., are:

Oil Temperature	Meter Constant
130 deg.	0.949
120	0.952
110	0.956
100	0.959
90	0.965

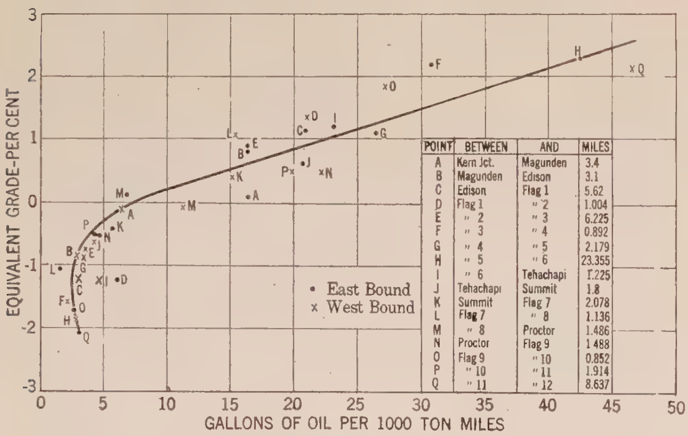
The time, fuel meter reading, fuel temperature, and location of train, were recorded at every start, grade change or other important point, and stop. The speeds were determined by counting engine driver revolutions. All grade changes at other than station points were marked by white flags—see profile, P. S. 321. Grade compensation for curvature is applied at 0.04 per cent grade per degree of curvature. The equivalent grades eastbound and westbound for the same section of track obviously are of opposite sign, and of different numerical value.

From the log sheets of the trip were tabulated: fuel metered, fuel consumed, fuel and water in tender; time running at normal speed, running slowly and standing. These sheets then were reduced to show for every section of the track: the train weight corrected for fuel and water consumed, the times between sidings, running through sidings, running between stations or flag points, and standing. Then by combination of these elements there were deduced: Total train resistances, horse power hours at drivers, thermal horse power-hours based on actual average thermal efficiency for the trip, and computed fuel vs. actual fuel burned. Based on Schmidt's tables, the train resistance for level tangent track was taken at 7 lb. per ton. The average thermal efficiency was determined from the total horse power-hours and the fuel burned when moving over sections where the total resistance was positive. A fair average standard time and fuel used to fire up, stand by, test air, and put engine away, were assumed for all trips.

The average gallons of fuel per thousand ton-miles, in both directions, for every section of track, but not corrected for variations in speed within a section, were determined under actual operating conditions of the test, and are shown in Fig 5. plotted against equiva-

lent grade; wherein the curve as drawn has been adjusted to give fuel requirements for constant speed. Thus is shown the fuel cost of acceleration, and how, in the stop, provided the brakes are not used, a large proportion of the work done in acceleration is made useful in moving the train over the track. This is indicated by points on the left of the curve; points on the right show increase fuel consumptions during acceleration.

It will be of interest to follow a train from Kern Junction to Summit. All freight trains stop at Kern Junction to check the register, and for orders. The grade from Kern Junction to Magunden being light, the acceleration is high, and the speed at Magunden averaged about 38 miles per hour. According to the curve the fuel consumption per 1000 ton-miles on a 0.1 per cent grade at constant speed would be 10.25 gallons. The actual fuel consumption as shown by "A" is 16.29 gallons. The difference (16.29 – 10.25 = 6.04) represents the fuel cost of acceleration. The grade from Magunden to Edison is 0.83 per cent. The



POINT	BETWEEN	AND	MILES
A	Kern Jct.	Magunden	3.4
B	Magunden	Edison	3.1
C	Edison	Flag 1	5.62
D	Flag 1	" 2	1.004
E	" 2	" 3	6.225
F	" 3	" 4	0.892
G	" 4	" 5	2.179
H	" 5	" 6	23.355
I	" 6	Tehachapi	1.225
J	Tehachapi	Summit	1.8
K	Summit	Flag 7	2.078
L	Flag 7	" 8	1.136
M	" 8	Proctor	1.486
N	Proctor	Flag 9	1 488
O	Flag 9	" 10	0.852
P	" 10	" 11	1.914
Q	" 11	" 12	8.637

FIG. 5—FUEL CONSUMED PER 1000 TON MILES ON VARIOUS GRADES

speed of the train was reduced from about 38 miles to 30 miles per hour. According to the curve the fuel consumption should be 20.75 gallons, but the actual fuel consumption is 16.43 gallons. The difference (20.75 – 16.43 = 4.32) represents the fuel saved by using a part of the kinetic energy in the train. From Edison to Flag No. 1 the grade is increased to 1.16 per cent, the speed of the train is reduced to about 26 miles per hour, and point "C" is at the left of the curve. From Flag No. 1 to Flag No.2 the grade is–1.22 per cent, the speed of the train is increased to 38 miles per hour, the kinetic energy is increased, and point "D" is at the right of the curve. From Flag No. 2 to Flag No. 3 the grade is 0.89 per cent, the speed is reduced to 31 miles per hour, and point "E" is at the left of the curve. From Flag No. 3 to Flag No. 4 the grade is 2.21 per cent, the speed is reduced to 17 miles per hour, and point "F" is at the left of the curve. From Flag No. 4 to Flag No. 5 the grade is 1.14 per cent, the speed is increased to 20 miles per hour, and point "G" is at the right of the curve. From Flag No. 5 to Flag No. 6 the grade is 2.31 per cent, the distance is over 23 miles, the drop in speed from 20 to 12 miles per hour has very little effect on the total fuel burned, and point "H" is on the curve. From Flag No. 6 to Tehachapi, the grade is 1.24 per cent, and although the train accelerated after passing Flag No. 6, which would tend to increase the fuel consumption, the train was brought to rest at Tehachapi and the kinetic energy in the train offset a part of the fuel that would have been burned at constant speed, and point "*I*" falls to the left of the curve. From Tehachapi to Summit the grade is 0.62 per cent. The train started from rest, therefore due to acceleration point "*J*" falls to the right of the curve. It is of interest to note that the actual test data illustrate the well known fact that kinetic energy can be exchanged for fuel and fuel for kinetic energy.

It is not considered that the results of this test should be depended upon for slight grades either positive or negative, because there is no section of level track between Bakersfield and Mojave. The curve has therefore been drawn with solid lines for grades greater than 0.5 per cent, both positive and negative, and dotted between these two grades. The dotted part of the curve should not be depended upon for accurate results.

A locomotive of lower thermal efficiency than the No. 3614 would burn more fuel for any given grade than that shown on the curve. The result would be a flatter curve. On the other hand a locomotive of higher thermal efficiency would burn less fuel than shown and the curve would be steeper. It is, therefore, apparent that the slope of the curve is a function of the efficiency, and the steeper the curve the higher the efficiency.

From the curve, the fuel required per 1000 ton-miles on a 2 per cent grade equals 38.0 gallons, and for a one per cent grade equals 23.3 gallons. The difference (38.0 – 23.3 = 14.7) represents the fuel burned moving a 1000 ton train one mile over a one per cent grade without friction; because both the 38.0 and the 23.3 gallons are for grade resistance plus train friction, the train friction being the same in each case, the difference is for a differential grade resistance of one per cent. A one per cent grade resistance is 20 pounds per ton. Then the work done in moving the given train one mile over a one per cent grade without friction equals $20 \times 1000 \times 5280 = 105{,}600{,}000$ foot pounds. This required 14.7 gallons of fuel or $14.7 \times 8 \times 18{,}000 \times 778.1 = 1{,}647{,}082{,}080$ foot pounds. The thermal efficiency equals $105{,}600{,}000/1{,}647{,}082{,}080 = 0.0641$, or 6.41 per cent. It will be seen at once that this method of determining engine thermal efficiency is independent of train resistance at driver tires which, at best, is difficult to determine accurately.

The method used above for determining efficiency is based on a known weight of train, a known grade resistance and test values for fuel consumption, and should be very nearly correct.

The fuel burned on a one per cent grade for grade and train resistance is 23.3 gallons. If the train resistance equals X then:

$$(20 + X)/X = 23.3/(23.3 - 14.7)$$

From which X equals 11.7 pounds per ton.

This does not check with the assumed 7 pounds per ton, shown in Table V, because the 7 pounds covers only rolling friction, and the 11.7 pounds is for rolling friction plus locomotive internal friction, such as pistons, valves, and other engine parts. If Schmidt's 7 pounds is correct for the rolling friction then the difference, (11.7 − 7), 4.7, is the locomotive internal friction; this friction for the given train of 1000 tons is equal to a drawbar pull of 4.7 × 1000 = 4700 pounds, or about 9.0 per cent of the total drawbar pull on the maximum grade of 2.31 per cent from Flag No. 5 to Flag No. 6.

As the negative grade increases, the fuel consumption is reduced until the negative grade resistance is numerically equal to the total frictional resistance of train and engine. The minimum fuel consumption of 2.5 gallons per mile as shown on the curve represents standby losses and should be about equal to the fuel burned standing on a siding with the train, which is 42.8 gallons per hour. Then 42.8/2.5 = 17.1 is the drifting speed of the train in miles per hour, that corresponds to the minimum consumption of fuel. The down grade speed limit for freight trains by order is 18 miles per hour. Evidently, then, there is a good compliance with orders. For heavy negative grades the fuel consumption is again increased, for pumping air for braking purposes.

The over-all efficiency determined by this test was 5.57 per cent. It is the ratio of the integrated foot-pounds of work done by the engine whenever the drawbar pull was positive, to the total energy in the fuel used over the same time. Apparently it is constant for all grades greater than 0.5 per cent.

For a long time it has been known that drifting as much as possible saves fuel. Except on positive grades only, seldom is it possible to drift to rest. Fig. 6 gives a measure of the saving that may be made by taking advantage of favorable opportunities. The kinetic energy, in terms of fuel, in a 1000 ton train moving at 50 miles per hour equals 27.74 gallons. If the engineer makes a sudden stop by heavy braking the greater part of this 27.74 gallons is lost in heat at the brake shoes. If his train schedule will permit him to drift down to 25 miles per hour before applying brakes the fuel equivalent for kinetic energy is 6.93 gallons, and 20.81 gallons of fuel will be saved. The curve shows that drifting to one-half of the normal running speed before applying brakes saves 75 per cent of the fuel equivalent for kinetic energy.

There has been much discussion of the question which train should take siding, when trains meet on a single-track line, that the maximum fuel economy should result. Many elements, other than fuel, enter into the total cost. The fuel burned chargeable to the meet is for two purposes; first for slowing down or stopping to throw switches, and second, for standby while waiting for the other train. The standby losses depend upon time rather than tonnage and have been discussed previously in the second group of factors.

As long as every movement of the train is in the normal direction that the train is traveling, only the extra fuel required for slow-downs or stops should be charged against the meet. Table III gives gallons of fuel burned running through sidings, distance in feet through sidings, weight of train, gallons of fuel that would have been burned moving the same distance on the main line, and the extra fuel burned. An analysis of results indicates that taking siding on a heavy grade was quite different from taking siding on a medium grade. The first group in Table No. 3 is for grades over 2 per cent, and the second group for grades less than 2 per cent. The average fuel cost of taking siding on grades of over 2 per cent is 18.3 gallons. For grades materially less than 2 per cent no extra fuel was burned. The trains do not move at a speed of over 12 miles per

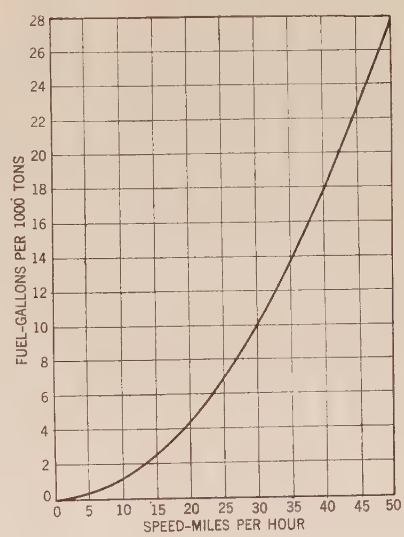


Fig. 6—Fuel Required to Accelerate 1000 Tons

Over-all thermal efficiency = 5.65 per cent

hour up heavy grades, so that the fuel required for acceleration is less than 2 gallons per 1000 ton train. Brakes are applied to hold the train rather than to stop the train. It is believed therefore that the extra fuel burned taking siding on heavy grades is due to the fact that the slow, heavy starting and pulling works the engine beyond its most efficient point, and in several cases the locomotive slipped its wheels. On light grades a freight train moves at a speed of 20 to 35 miles per hour. But trains take siding at low speed on all grades. The drawbar pull per ton is greater at high speed than at low speed, and the fuel saved by moving through sidings at a low and more efficient speed offsets the fuel loss due to braking. It is felt that these results should be applied in general with caution, because fuel used varied between wide limits.

The engineer is held responsible for the fuel charged

TABLE I.

GRADE AND CURVATURE—TEHACHAPI

EASTBOUND

Location From	Location To	Distance Miles	Rise Feet	Total Curvature Degrees	Average Grade Per cent	Average Curvature Degrees	Per cent Grade Correction for Curvature*	Equivalent Grade Per cent
Kern Jct.	Magunden	3.4	17.8	..	0.10	..	..	0.10
Magunden	Edison	3.1	135.7	..	0.83	..	..	0.83
Edison	Flag 1	5.62	342.9	17.5	1.16	0.06	..	1.16
Flag 1	Flag 2	1.004	−68.9	99.3	−1.30	1.9	0.08	−1.22
Flag 2	Flag 3	6.225	268.9	589.5	0.82	1.8	0.07	0.89
Flag 3	Flag 4	0.892	89.0	376.3	1.89	8.0	0.32	2.21
Flag 4	Flag 5	2.179	115.0	417.5	1.00	3.6	0.14	1.14
Flag 5	Flag 6	23.355	2575.0	6751.0	2.09	5.48	0.22	2.31
Flag 6	Tehachapi	1.225	79.5	17.6	1.23	0.3	0.01	1.24
Tehachapi	Summit	1.8	58.5	..	0.62	..	..	0.62
Summit	Flag 7	2.078	−46.0	..	−0.42	..	..	−0.42
Flag 7	Flag 8	1.136	−65.0	13.6	−1.08	0.2	0.01	−1.07
Flag 8	Proctor	1.486	5.5	46.4	0.07	0.6	0.02	0.09
Proctor	Flag 9	1.488	−39.5	..	−0.50	..	..	−0.50
Flag 9	Flag 10	0.852	−80.0	98.3	−1.78	2.2	0.09	−1.69
Flag 10	Flag 11	1.914	−50.0	27.9	−0.50	0.3	0.01	−0.49
Flag 11	Flag 12	8.637	−960.00	547.7	−2.10	1.2	0.05	−2.05

Total distance 67.8

*Correction for curvature is 0.04 per cent grade for each degree of average curvature.

TABLE 1 (*Continued*)

WESTBOUND

Location From	Location To	Distance Miles	Rise Feet	Total Curvature Degrees	Average Grade Per cent	Average Curvature Degrees	Per cent Grade Correction for Curvature	Equivalent Grade Per cent
Flag 12	Flag 11	8.637	960.0	547.7	2.10	1.2	0.05	2.15
Flag 11	Flag 10	1.914	50.0	27.9	0.50	0.3	0.01	0.51
Flag 10	Flag 9	0.852	80.0	98.3	1.78	2.2	0.09	1.87
Flag 9	Proctor	1.488	39.5	..	0.50	..	..	0.50
Proctor	Flag 8	1.486	−5.5	46.4	−0.07	0.6	0.02	−0.05
Flag 8	Flag 7	1.136	65.0	13.6	1.08	0.2	0.01	1.09
Flag 7	Summit	2.078	46.0	..	0.42	..	..	0.42
Summit	Tehachapi	1.8	−58.5	..	−0.62	..	..	−0.62
Tehachapi	Flag 6	1.225	−79.5	17.5	−1.23	0.3	0.01	−1.22
Flag 6	Flag 5	23.355	−2575.0	6751.0	−2.09	5.48	0.22	−1.87
Flag 5	Flag 4	2.179	−115.00	417.5	−1.00	3.6	0.14	−0.86
Flag 4	Flag 3	0.892	−89.0	376.3	−1.89	8.0	0.32	−1.57
Flag 3	Flag 2	6.225	−268.9	589.5	−0.82	1.8	0.07	−0.75
Flag 2	Flag 1	1.004	68.9	99.3	1.30	1.9	0.08	1.38
Flag 1	Edison	5.62	−342.9	17.5	−1.16	0.06	..	−1.16
Edison	Magunden	3.1	−135.7	..	−0.83	..	..	−0.83
Magunden	Kern	3.4	−17.8	..	−0.10	..	..	−0.10

TABLE II.

FUEL PER 1000 TON-MILES—TEHACHAPI

Section		Gallons of Fuel per 1000 Ton-Miles Eastbound	Westbound
Kern Jct.	Magunden	16.29	6.31
Magunden	Edison	16.43	2.93
Edison	Flag 1	20.86	3.13
Flag 1	Flag 2	6.11	21.03
Flag 2	Flag 3	16.31	3.50
Flag 3	Flag 4	30.71	2.24
Flag 4	Flag 5	26.39	3.35
Flag 5	Flag 6	42.43	2.77
Flag 6	Tehachapi	23.17	4.71
Tehachapi	Summit	20.59	4.24
Summit	Flag 7	5.62	15.19
Flag 7	Flag 8	1.62	15.33
Flag 8	Proctor	6.73	11.27
Proctor	Flag 9	4.35	22.14
Flag 9	Flag 10	2.70	27.17
Flag 10	Flag 11	4.30	19.82
Flag 11	Flag 12	3.06	46.56

to road service. Part of this fuel is burned in the actual progression of the train; the remainder is burned in locomotive or train movements incident thereto. The fuel burned in actual train movements depends upon the efficiency of the locomotive and the skill of the engineer. The fuel burned for miscellaneous purposes depends upon traffic conditions and the general efficiency of the division organization in handling traffic. In this discussion the ratio between the fuel burned moving the train and the total fuel charged to road service is called "Operating Efficiency, Fuel." The operating efficiencies for each trip, averages eastbound and westbound, and for all test trips, are shown in Table IV.

Such a ratio is a measure of the operating efficiency of the division organization. The high value determined by this test, 92.5 per cent, indicates a cooperation

TABLE III.

FUEL COST OF MEET PER 1000 TON TRAIN—TEHACHAPI

Trip	Fuel Burned Through Siding Gallons	Distance Through Siding Feet	Weight of Train Tons	Fuel per 1000 Tons Gallons	Fuel for Equivalent Distance Main Line Gallons	Fuel Cost of Meet Gallons	Station
			GRADES OVER 2 PER CENT				
2—E	44	4374	1030	42.7	34.0	8.7	Allard
4—E	70	4544	1018	68.8	35.2	33.6	Woodford
6—E	45	4544	1001	45.0	35.2	9.8	Woodford
7—E	45	4544	1021	44.0	35.2	8.8	Woodford
8—E	51	4544	1018	50.2	35.2	15.0	Woodford
9—E	89	5468	1020	87.2	42.4	44.8	Rowen
9—E	45	4291	1019	44.2	33.4	10.8	Cable
3—W	40	4013	1067	37.5	31.1	6.4	Warren
7—W	65	4287	1089	59.7	33.2	26.5	Fram
	Totals		9283			164.4	
	Average		1031			18.3	per 1000 ton train.
			LIGHT GRADES				
1—E	25	4411	1021	24.5	20.0	4.5	Bena
1—E	18	4305	1016	17.7	26.1	6.4	Ilmon
4—E	21	4411	1020	20.6	20.0	0.6	Bena
8—W	22	5315	1064	20.6	22.2	−1.6	Cameron
					Total	−2.9	
					Average	−0.7	

TABLE IV.

OPERATING EFFICIENCY—FUEL—TEHACHAPI

Ratio between fuel burned moving train and total fuel burned from 30 minutes before leaving initial terminal until 10 minutes after arrival at home terminal.

Trip	Operating Efficiency Per Cent
1—E	92.6
2—E	96.1
3—E	96.5
4—E	93.9
6—E	89.5
7—E	95.1
8—E	95.7
9—E	95.2
Average Eastbound	94.3
1—W	88.3
3—W	90.7
4—W	87.1
5—W	87.7
6—W	93.0
7—W	89.6
8—W	85.1
Average Westbound	88.7
Weighted Average Eastbound and Westbound	92.5

between dispatchers and train crews not often realized. It indicates also a very small margin of possible gain between steam locomotives, well handled, and the theoretical limit of the electric locomotive, 100 per cent less engine auxiliaries. A second track would undoubtedly raise this ratio; but single-track operation does not excuse a low efficiency.

Many changes have been made in locomotive design during the past few years. Larger units, higher boiler pressure, superheaters, and, more recently, the addition of feed water heaters and boosters, have gone a long way toward increasing efficiency. Though the locomotive used for this test is one of the well known types for heavy mountain service, and was tested under its most economical load, yet the average thermal efficiency is less than 6 per cent; hence a slight numerical increase in this efficiency would result in a tremendous saving in fuel. For example, the Super Power Survey showed an expected fuel saving of 67 per cent in freight service, which means a thermal efficiency of about 8.5 per cent. Whether in electric service such a point is within reach, others must determine. In making such comparisons it is necessary to take account of the ratio, revenue freight weight to total train weight. In this study it was 0.743. In electric service it may be very different. The mechanical engineers of this country will hardly admit that they are satisfied with even the best engine yet designed. The efficiency determined during this test

TABLE V.

LOCOMOTIVE THERMAL EFFICIENCY—TEHACHAPI

FOR A TRAIN OF 1000 TONS—EASTBOUND

Location From	Location To	Distance Miles A	Distance Feet B	Equivalent Grade Per Cent C	Grade Resistance Lb./Ton D C × 20	Total Resistance Lb./Ton E D + 7
Firing up 90 min.		..	..	..	..	..
Standby 60 min.		..	..	..	..	..
Testing air 30 min.		..	..	..	..	..
Bakersfield	Kern Jct.	0.7	3700	0.07	1.4	8.4
Kern Jct.	Magunden	3.4	17950	0.1	2.0	9.0
Magunden	Edison	3.1	16370	0.83	16.6	23.6
Edison	Flag 1	5.62	29670	1.16	23.2	30.2
Flag 1	Flag 2	1.004	5300	−1.22	−24.4	−17.4
Flag 2	Flag 3	6.225	32860	0.89	17.8	24.8
Flag 3	Flag 4	0.892	4710	2.21	44.2	51.2
Flag 4	Flag 5	2.179	11500	1.14	22.8	29.8
Flag 5	Flag 6	23.355	123300	2.31	46.2	53.2
Flag 6	Tehachapi	1.225	6470	1.24	24.8	31.8
Tehachapi	Summit	1.8	9500	0.62	12.4	19.4
Summit	Flag 7	2.078	10970	−0.42	−8.4	−1.4
Flag 7	Flag 8	1.136	6000	−1.07	−21.4	−14.4
Flag 8	Proctor	1.486	7850	0.09	1.8	8.8
Proctor	Flag 9	1.488	7860	−0.50	−10.0	−3.0
Flag 9	Flag 10	0.852	4500	−1.69	−33.8	−26.8
Flag 10	Flag 11	1.914	10100	−0.49	−9.8	−2.8
Flag 11	Flag 12	8.637	45600	−2.05	−41.0	−34.0
Flag 12	Mojave	0.709	3740	−1.15	−23.0	−16.0
Mojave to Enginehouse 60 min.			..	..	..	..
Standing at Stations 80 min.			..	..	..	..

is lower than many published values, but, as a rule, such tests are made with picked locomotives, especially adjusted for the test and operated by the best crews.

It is not desired to give the impression that the values of factors given as the result of this investigation are absolute and applicable to all conditions. It is believed that this method of testing attacks the problem from an entirely different angle, from which it is possible to make, of certain factors, analysis in detail that has not been possible by other methods.

TABLE V. PART 2
EASTBOUND

Distance Miles A	Total Weight of Train Tons F	Total Tractive Effort Pounds G E × F	Million Ft. Lb. at Drivers Constant Speed H B × G/10^6	H. P. Hrs. at Drivers Constant Speed I H/1.98	Thermal H. P. Hrs. for 5.57 Per cent Efficiency J + only 1/0.0557	Computed Fuel Gallons K J/0.01765
..	..	..	..	..	..	90.0
..	..	..	..	..	..	20.0
..	..	..	..	..	..	21.0
0.7	1000	8400	31.1	15.7	281.8	4.9
3.4	1000	9000	161.6	81.6	1464.0	25.5
3.1	1000	23600	386.3	195.1	3502.0	60.9
5.62	1000	30200	896.0	452.6	8121.0	141.4
1.004	1000	−17400	−92.2	−46.6	..	6.0
6.225	1000	24800	815.0	411.7	7390.0	128.6
0.892	1000	51200	281.2	121.8	2186.0	38.1
2.179	1000	29800	342.7	173.1	3106.5	54.1
23.355	1000	53200	6559.0	3312.0	59455.0	1034.7
1.225	1000	31800	205.3	103.9	1865.0	32.5
1.8	1000	19400	184.3	93.1	1671.0	29.1
2.078	1000	−1400	−15.4	−7.8	..	11.0
1.136	1000	−14400	−86.4	−43.6	..	2.5
1.486	1000	8800	69.1	34.9	626.3	10.9
1.488	1000	−3000	−23.6	−11.9	..	7.0
0.852	1000	−26800	−120.6	−60.9	..	2.5
1.914	1000	−2800	−28.3	−14.3	..	8.5
8.637	1000	−34000	−1551.0	−783.0	..	29.7
0.709	1000	−16000	−59.8	−30.2	..	4.7
..	..	..	..	..	..	20.0
..	..	..	..	..	..	57.0
						1840.6

TABLE V. PART 3
LOCOMOTIVE THERMAL EFFICIENCY—TEHACHAPI
FOR A TRAIN OF 1000 TONS—WESTBOUND

Location From	Location To	Distance Miles A	Distance Feet B	Equivalent Grade Per Cent C	Grade Resistance Lb/Ton D C × 20	Total Resistance Lb/Ton E D + 7
Firing up 60 min.		..	..	..	..	..
Standby 30 min.		..	..	..	..	..
Testing air 30 min.		..	..	..	..	..
Mojave	Flag 12	0.709	3740	1.15	23.0	30.0
Flag 12	Flag 11	8.637	45600	2.15	43.0	50.0
Flag 11	Flag 10	1.914	10100	0.51	10.2	17.2
Flag 10	Flag 9	0.852	4500	1.87	37.4	44.4
Flag 9	Proctor	1.488	7860	0.50	10.0	17.0
Proctor	Flag 8	1.486	7850	−0.05	−1.0	6.0
Flag 8	Flag 7	1.136	6000	1.09	21.8	28.8
Flag 7	Summit	2.078	10970	0.42	8.4	15.4
Summit	Tehachapi	1.8	9500	−0.62	−12.4	−5.4
Tehachapi	Flag 6	1.225	6470	−1.22	−24.4	−17.4
Flag 6	Flag 5	23.355	123300	−1.87	−37.4	−30.4
Flag 5	Flag 4	2.179	11500	−0.86	−17.2	−10.2
Flag 4	Flag 3	0.892	4710	−1.57	−31.4	−24.4
Flag 3	Flag 2	6.225	32860	−0.75	−15.0	−8.0
Flag 2	Flag 1	1.004	5300	1.38	27.6	34.6
Flag 1	Edison	5.62	29670	−1.16	−23.2	−16.2
Edison	Magunden	3.1	16370	−0.83	−16.6	−9.6
Magunden	Kern Jct.	3.4	17950	−0.10	−2.0	5.0
Kern Jct.	Bakersfield	0.7	3700	−0.07	−1.4	5.6
Bakersfield to Enginehouse 60 min.				..	..	..
Standing at station 106 min.				..	..	..

TABLE V. PART 4
WESTBOUND

Distance Miles A	Total Weight of Train Tons F	Total Tractive Effort Pounds G E × F	Million Ft. Lb. at Drivers Constant Speed H B × G/10^6	H. P. Hrs. at Drivers Constant Speed I H/1.98	Thermal H. P. Hrs. for 5.57 Per cent Efficiency J + only 1/0.0557	Computed Fuel Gallons K J/0.01765
..	..	..	..	..	..	90.0
..	..	..	..	..	..	10.0
..	..	..	..	..	..	21.0
0.709	1000	30000	112.2	56.7	1017.5	17.7
8.637	1000	50000	2281.0	1151.5	20670.0	259.7
1.914	1000	17200	173.8	87.7	1574.7	27.4
0.852	1000	44400	199.3	101.0	1811.3	31.6
1.488	1000	17000	133.6	67.5	1211.2	21.1
1.486	1000	6000	47.1	23.8	427.1	7.4
1.136	1000	28800	172.8	87.3	1566.7	27.3
2.078	1000	15400	169.0	85.3	1531.7	26.6
1.8	1000	−5400	−51.3	−25.9	..	9.9
1.225	1000	−17400	−112.6	−56.9	..	6.8
23.355	1000	−30400	−3748.0	−1892.5	..	86.2
2.179	1000	−10200	−117.3	−59.2	..	9.1
0.892	1000	−24400	−115.0	−58.0	..	2.1
6.225	1000	−8000	−262.9	−132.8	..	26.0
1.004	1000	34600	183.4	92.6	166.7	28.9
5.62	1000	−16200	−480.7	−242.7	..	24.2
3.1	1000	−9600	−157.2	−79.3	..	10.5
3.4	1000	5000	89.8	45.3	813.7	14.1
0.7	1000	5600	20.7	10.5	187.8	3.3
..	..	..	..	..	..	20.0
..	..	..	..	..	..	75.5
						956.4

Undiscriminating application of the results of this study easily may produce extremely inaccurate results; for example, where the conditions surrounding the particular problem bear only a remote resemblance to those of the line over which the tests were made. Weather, grade, service and many other conditions have their effect upon train operation. Similar tests should be made in passenger and freight, mountain and valley service, also with other types of power.

LIST OF FACTORS

	Unit	Value
First Group		
Fuel to fire up with water at 60 deg. fahr.	Gallons	167
Fuel to fire up with water at 120 deg. fahr.	Gallons	131
Fuel to fire up with water at 180 deg. fahr.	Gallons	96
Second Group		
Fuel to hold under steam, in enginehouse, without auxiliaries—per hour	Gallons	17.4
Fuel to hold under steam, out-of-doors, with auxiliaries—per hour	Gallons	36.6
Fuel to hold train on siding—per hour	Gallons	42.8
Third Group		
Train resistance—Hood & Schmidt	Pounds	7
Total train and locomotive resistance—level track	Pounds	11.7
Average overall thermal efficiency	Per cent	5.57
Maximum overall thermal efficiency	Per cent	6.41
Fuel per 1000 ton miles per per-cent grade without friction	Gallons	14.7
Locomotive internal friction in terms of maximum drawbar pull	Per cent	9
Fuel cost of meet per 1000 ton train on grades of 2 per cent or over	Gallons	18.3
Fuel cost of meet per 1000 ton train on light grades	Gallons	0.0
Average Operating Efficiency—Fuel	Per cent	92.5

The Production of Porcelain for Electrical Insulation—I

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Review of the Subject.—*This series of articles is presented with a view of acquainting the electrical engineer with the composition of porcelain, the raw materials, and processes employed in its manufacture, and with the structure and the physical properties of the finished product. The principles underlying the art will be discussed as well as the reasons for using certain materials or certain processes.*

Recent developments in porcelain for automotive purposes have clearly demonstrated that the transmission porcelain of the future will be an improvement over that of the porcelain of today, provided however, that the consumer of transmission porcelain will be willing to pay the increased cost, or provided the manufacturer will be able to lower his cost on the improved product when sufficiently developed. The fact that the porcelain used in transmission work today would make only inferior spark plugs makes it safe to predict this future improvement in transmission porcelain.

The present article deals briefly with the history of porcelain and its definition.

Generally porcelain is made of a mixture of ground feldspar, a mineral which melts to glass and makes the porcelain vitreous when fired; clay which makes it possible to form the unfired porcelain and have it retain its shape; and fine silica sand or quartz which acts as a filler or non-plastic material. These three materials are mentioned several times before they are described in detail but this brief description is sufficient for the present.

The beginning of a description of ceramic raw materials is given.

The writer wishes to express his thanks to Mr. A. V. Bleininger for his cooperation and suggestions in preparing these articles. Also to Prof. Albert Peck for his assistance in preparing and discussing the photomicrographs.

* * * * *

History

PORCELAIN is known to have been made by the Chinese about 1000 years ago. They developed the art to a high plane of artistic excellence. It was this porcelain, which, when brought to Europe, caused many potters in a number of countries to attempt its reproduction. For centuries these attempts proved unsuccessful and the best that could be done by the Italian, French, and Dutch schools of artisans and artists was to create a type of faience pottery in which the coarse color of the clay body was hidden by an opaque, white enamel containing tin oxide. It was not until 1709 that Boettcher discovered the use of kaolin and first made a yellowish but vitrified material which could be considered a type of porcelain. In England Josiah Wedgwood in 1759 produced a type of semi-vitreous pottery, known as Queens Ware. In France at a much later date a frit porcelain was made in which kaolin and ground quartz were cemented together in firing by means of a fusible glass or frit. The knowledge of the art of porcelain making soon spread over Europe and finally resulted in two types: the so-called hard porcelain of continental Europe, composed of kaolin or clay, ground quartz and feldspar, a mixture which is vitrified at about 1400 deg. cent. (2552 deg. fahr. a bright white heat); and the bone china of England, consisting of white burning clay, feldspar, introduced through the so-called Cornish stone, and calcined or burned bone ash. The latter porcelain known as bone china is caused to vitrify at about 1280 deg. cent. (2336 deg. Fahr.). For electrical purposes only the hard porcelain is used in Europe; however, the American product although made at slightly lower temperatures than 1400 deg. cent. is considered superior.

In the United States porcelain for electrical insulation was developed about 1895 from the so-called semi-vitreous tableware, composed approximately of 50 per cent of kaolin and ball clay, 14 per cent of feldspar and 36 per cent of ground quartz. By reducing the content of quartz and increasing that of feldspar, a vitrified body was produced which matured at about 1330 deg. cent. (2426 deg. fahr.). In such a composition the amounts of feldspar and quartz are approximately 30 and 20 per cent respectively.

Fig. 1—Clay Mining Operation

Usually clays have to be washed or cleansed before being shipped to the consumer. Sand and other coarse particles are settled out in water, the fine clay being floated and later de-watered.

Definition of Porcelain

The general composition of porcelain has already been indicated as being essentially a mixture of clay substance, principally kaolin, feldspar and quartz. These minerals, intimately blended, are fired to a temperature at which the feldspar fuses to a glass and in doing so cements together the two more refractory constituents. Porcelain may thus be said to be an agglomerate of clay and quartz held together in a matrix of molten feldspar at least as far as the lower firing temperatures of the usual tableware porcelains are concerned. Such a mass is non-absorbent, *i. e.*, when immersed in water, even under diminished pressure, practically none is taken up. Again, thin sections of the material transmit some light thus showing that there is present a continuous translucent glass phase.

These two qualities then are peculiar to porcelain. The color of the material is generally but not necessarily white. Examining a thin petrographic section[1] of porcelain under the microscope, especially with polarized light,[2] we are able to discern the fragments of fine quartz surrounded by glass and clay substance which may or may not be dissociated into a new crystalline mineral constituent. It will also be noted that the quartz grains are subject to a solution process inasmuch as many of them have lost their sharp edges and have become rounded. Indeed, very fine grains may disappear altogether. It is evident therefore that the feldspar glass behaves as a powerful solvent, tending to dissolve the quartz. This solution may actually be carried to completion in high fire porcelains.

At the temperatures to which transmission porcelain is burned 1350 deg. cent. to 1390 deg. cent. (2462 deg. fahr. to 2502 deg. fahr.) the solution of the quartz has become quite noticeable and the crystalline development shows more distinctly particularly at the higher temperature mentioned.

Parallel with the dissolving of the quartz goes the dissociation of the clay substance into a new and frequently crystalline compound, sillimanite,[3] (sil'li-man-ite) which may be plainly recognized under the microscope.

But both the solution of quartz and the formation of sillimanite are not necessary qualifications of a porcelain, nor is it necessary that feldspar should be present or even quartz. It is quite possible to produce the incipient fusion required by means of other fluxes and it is equally true that quartz may be replaced by other mineral constituents of a more or less inert nature. Clay, on the other hand, is a necessary component since its presence is indispensable in the initial molding of the ware. We might define porcelain then to be a ceramic product usually light colored, which is completely vitrified and is translucent in thin sections.

It is evident from what has already been said that porcelains may have a wide range of composition and that hence there must necessarily be a variety of types which possess certain characteristics. As the composition varies so must also the firing temperature vary since it is evident that a material carrying a high percentage of feldspar can be matured, or properly fired to a vitreous porcelain, at a lower temperature than one with less flux. Accordingly we may have porcelains high or low in clay substance, high or low in fluxes and high or low in quartz. The properties of one porcelain shade into those of another with gradual changes in composition.

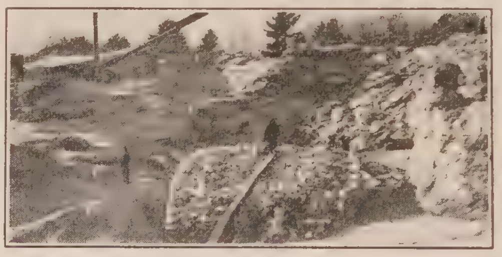


Fig. 2—Quarrying Feldspar

This material is later ground extremely fine and incorporated into the mixture with clay and ground quartz. It acts as a flux melting to a glass when the ware is fired in kilns, and not only binding or cementing the particles of clay and quartz together to form porcelain but also actually dissolving part of the other ingredients and forming new compounds.

Ceramic Raw Materials

The principal raw materials of porcelain are clay, feldspar and quartz but there are to be considered also other constituents, such as calcium carbonate, magnesium carbonate, alumina, zirconium oxide, zirconium silicate and sillimanite, which are coming into use for special purposes in the modern development of the art.

Clays

There are to be considered principally two types, the less plastic, very white burning materials known as kaolins or china clays, and the very plastic, creamish or yellow burning, ball clays.

The kaolins may again be divided into two classes, those of primary, geological origin and those laid down as secondary deposits. The former type of kaolin is found in contact with the parent, igneous rock, from which it has been formed through natural decomposition

1. A thin transparent section of the specimen (about 0.001 inch thick) for use under the microscope for studying the structure and mineralogical constituents of same.

2. "Mineralogy" by Kraus and Hunt, p. 107 state in part as follows:

"Nature of Polarized Light—According to the undulatory theory, light is assumed to be a form of energy transmitted in waves in the ether, which pervades all things and space. The propagation of light takes place according to the laws of wave motion, the ether particles vibrating at right angles to the direction of propagation. The velocity of propagation has been determined to be about 186,000 miles per second.

"In the case of ordinary light, the vibration of the ether particles takes place in a plane at right angles to the direction in which the light is propagated, but the vibration direction in this plane is constantly changing.

"In plane polarized light, the vibrations take place in a definite direction within the plane and at right angles to the direction of propagation. Plane polarized light may be produced in three ways."

Certain substances are transparent to vibrations in one plane, and opaque to those in the plane at right angles to this, so that in transmitting the light those vibrations are selected to which this plane corresponds. The plane of polarization is altered or rotated by the passage of polarized light through a quartz crystal built into the microscope. Owing to interferences, crystals show remarkable colors when polarized light is passed through them and it is hence valuable in the investigation of rock structure.

3. Sillimanite will be described in detail later. It is of interest at this time to note briefly that clay contains one atom of alumina and two of silica and that, at the proper firing temperature this breaks up or dissociates into the sillimanite crystal made up of one atom of alumina and one atom of silica, the other atom of silica going into solution in the glassy feldspar.

$Al_2O_3, 2\,SiO_2 + \text{heat} = Al_2O_3, SiO_2\ \text{(Sillimanite)} + SiO_2$

processes. It is generally accepted that these clays are formed from the feldspar minerals which may be represented by the mineral orthoclase or microcline, K_2O Al_2O_3 $6SiO_2$. The feldspar, through leaching processes, is finally converted to the hydrous mineral, Al_2O_3 $2SiO_2$ $2H_2O$, known as kaolin, corresponding to the percentage composition of 47 silica, 39 alumina and 14 of chemically combined water. The decomposition process extends usually to the surface depths of the original granite or other type of igenous rock but in some localities as in Cornwall, England, the gaseous agencies at work arose from deep seated sources. In this locality therefore the deposits are deeper than those found in the United States, in North Carolina, Maryland and Pennsylvania.

The primary kaolins are composed of crystalline kaolin fragments but to a still greater extent of particles which are so small that they can be barely recognized under the high-power microscope and which cling together to form aggregates or clusters. The plasticity or the property which enables the kaolin to be molded is sufficient for the purpose but the bonding power of the material, that is, its power to cement together inert, non-plastic particles is quite feeble. This is to be ascribed to the fact that the component particles, while very small, still are larger than those making up the other types of clay and are of the order of 0.005 mm. (0.0002 inch) in diameter. We are dealing hence with a coarsely dispersed system of clay grains, and the mass requires about 30 per cent of water, expressed in terms of the dry weight of the clay in assuming the plastic state. A clay is said to be in the plastic state when it is wet enough to be modeled into any desired shape. These kaolins yield up their water readily upon drying and contract in volume, proportionately to the amount of water evaporated, down to the point at which the clay particles come in actual contact. The water which is driven off during the contraction is called shrinkage water and that remaining, pore water, as it fills the pores between the particles of clay after they have come in contact. The rate of evaporation of most of the water held by clay is practically equal to that of free water.

The kaolins laid down as secondary deposits are primary materials removed from the original place of deposition by the action of water currents. During this transportation process the clays necessarily come in contact with iron carrying minerals and hence become more or less contaminated by them. In addition the attrition and grinding action involved has brought about a decided reduction in the fineness of the grains, causing the clays to become more plastic and workable. Such secondary kaolin deposits are those of Georgia and Florida. The clay particles in these are not only exceedingly fine but also of remarkable uniformity in size which, however, is not a desirable condition, since it does not contribute towards maximum bonding power. As a result we find that these clays are stronger than the kaolins or china clays but much inferior in this respect to the so-called ball clays. The shrinkage of the secondary kaolins upon drying is quite large, amounting to about 30 per cent of the original volume. As a result they are inclined to crack or check under the strain of this large contraction unless the drying operation is carefully controlled.

The plastic bond or *ball clays* constitute the third group of clays used in the manufacture of porcelain and they represent by far the most powerful cementing materials for the bonding together of the non-plastic components. These clays are not only secondary clays, geologically speaking, but have been laid down either simultaneously with or in contact with material high in carbon of vegetable origin. In addition to the great inherent fineness of these clay grains the presence of this carbonaceous matter has resulted in building up not only well-developed plasticity but great bonding power as well. These materials, owing to the transporting

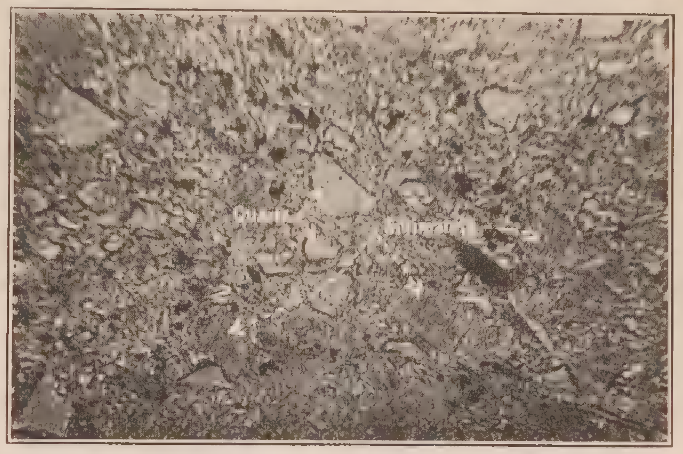


Fig. 3—Photomicrograph of a Thin Section of Insulator Porcelain Magnified 150 Times

This shows coarsely ground flint partly dissolved. Also fairly large and numerous areas of sil-li-man-ite needle crystals embedded in a glassy matrix of molten feldspar and other ingredients which have been dissolved. The sillimanite is a product developed from the clay during firing and its character and quantity has a marked effect upon the finished product. The black spots are holes in the porcelain which is ground exceedingly thin for microscopic examination.

processes they have undergone and their mode of sedimentation in swampy regions, have accumulated considerable amounts of iron and some other impurities and hence fire to a creamish or yellowish color. For the same reason, they fire to a dense structure at a comparatively low temperature unlike the kaolins which are refractory in nature and remain porous even at high furnace temperatures.

It is the chief function of these clays to bond together the non-plastic components of the porcelain and to impart to the mixture sufficient strength to withstand handling in the dry state. The mechanical strength of the ball clays may be illustrated by the fact that bars made from a one to one mixture of such a clay and a non-plastic may show a transverse strength of as much as 600 pounds per square inch. Owing to the

creamish or grayish color which they impart to the porcelain the amount of ball clay used is limited to the smallest amount possible. The best types of these plastic bonding materials are the ball clays from North and South Devonshire, and Dorset, England. There are also ball clays found in Tennessee and Kentucky.

Owing to the dense structure the water of plasticity escapes from the ball clays at a much lower rate than is the case with the more open grained kaolins and the drying process must hence be conducted with still greater care.

The fluxes present in these clays cause them to vitrify at a relatively low temperature and for this reason they promote also the vitrification of the porcelain mixture to which they have been added.

The following are typical analyses of various clays:

	Theoretical analysis of pure Kaolinite	China Clays or Kaolins		Ball or Plastic Clays	
		(a)	(b)	(a)	(b)
Silica	46.5	45.0	51.4	47.4	50.5
Alumina	39.6	37.8	28.8	34.2	32.8
Iron Oxide		1.2	1.1	1.4	1.3
Titanium Oxide		0.1	1.5	1.1	0.9
Calcium Oxide		0.2	0.2	0.4	0.6
Magnesium Oxide		0.2	0.4	0.6	0.4
Potassium Oxide		1.5	0.8	1.8	3.6
Sodium Oxide		1.3	1.8	0.8	0.9
Water of Crystallization	13.9	12.8	14.0	12.4	9.2
Total	100.0	100.1	100.0	100.1	100.2

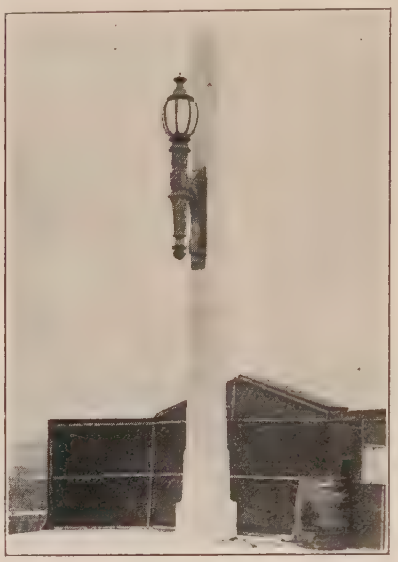
"GREAT WESTERN GATEWAY"

Structure Which Will Span Mohawk River at Schenectady N. Y., to Have Illumination System of Great Beauty and Exceptional Efficiency

In keeping with its importance as a link in one of the country's principal routes of vehicular traffic, the great concrete bridge which the State of New York is constructing across the Mohawk river between Schenectady and the village of Scotia will be one of the best lighted structures of the kind in the world.

Ornamental luminous arc lamps held by brackets attached to obelisks rising from the bridge will be used, both the lamps and the brackets being of bronze. The lamps will be of 1500 candle-power, 6.6 amperes, and will be enclosed in eight-panel globes. The obelisks to which the brackets will be fastened will rise from the parapets of the bridge to a height of 21 feet, and will be spaced at intervals of approximately 100 feet. They will be placed opposite one another, not staggered. The height of the light source above the roadway will be 17 feet. Not only will there be an abundant supply of light on the roadway, but the lanterns will present a beautiful appearance to those approaching the bridge. This lighting is a continuation of the luminous arc system now in use on State Street. The lamps will consume 532 watts. Current will be carried to the lamps by No. 8 cable, rubber covered and lead sheathed, leading to the bases of the obelisks through conduit installed in the concrete. Standard absolute cutouts will be installed.

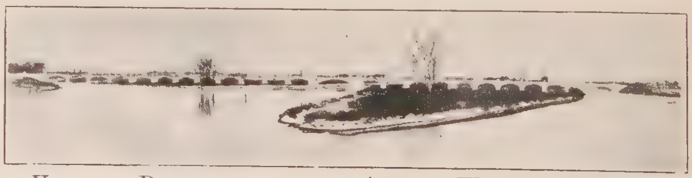
It is predicted that the lighting system will attract the interest and attention of engineers from far and wide as it will exemplify the very best in bridge illumination. Plans for it were worked out by State Engineer and Surveyor Frank M. Williams in conjunction with the Illuminating Engineering Laboratory of the General Electric Company at Schenectady.



Lighting Unit

The bridge will be 4515 feet long. It is of reinforced concrete construction, and will cost about $2,500,000, the state defraying the expense and the city of Schenectady and the village of Scotia aiding in the matter of approaches. It is expected that it will be completed by autumn of next year.

Since the days of Indian traders and pioneers, Schenectady has been the portal through which westbound travel and commerce has entered the pass through the Appalachians made by the Mohawk river.



View of Bridge as it will Appear When Completed

Hence this structure is appropriately called the "Great Western Gateway Bridge."

It will replace the present inadequate and unsatisfactory bridge constructed over 40 years ago, which occupies the site of the original structure, built in 1808, and which necessitates a detour around three sides of an irregular oblong. The new bridge will lead directly from the foot of State Street, Schenectady's main business thoroughfare, to the principal street of Scotia, which continues into the highway to Amsterdam and the west.

Public Address Systems

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THIS paper aims to present the problems encountered in the development of electrical systems for amplifying the voices of public speakers and music; and to describe the equipment as brought to a commercial state and now in use in the United States and various other countries.

The two main requirements of a successful public address or loud speaking system are, first, that it shall reproduce the sounds, such as speech or music, faithfully; and second, that this faithful reproduction shall be loud enough and sufficiently well distributed, for all of the audience to hear it comfortably. Most of the development work has been directed toward obtaining these two results under the various conditions which surround the operation of these systems.

The faithful and natural reproduction of sound depends upon many factors, of which the following are some of the more important: The acoustics of the space in which the sound originates, the characteristic of the loud speaking system itself and the acoustics of the space in which the sound is reproduced. Where the sound is picked up and reproduced in the same space, as is the case when the speaker is using one of these systems to address a large audience locally, there is a reaction between the horns and the transmitter or pick-up mechanism which is controlled by the acoustic conditions under which the system is operated.

Acoustics of the Space

In connection with the acoustics of the space in which the sound originates, or in which it is reproduced, four factors stand out. These concern the effects of reverberation, of echo, of resonance, and of diffraction. In the specific cases where the sound is reproduced in the same space or room in which it originates, another effect is encountered, which has generally been termed "singing," and is evidenced if sufficiently great by the emission of a continuous note from the equipment.

Reverberation is caused by reflection and is evidenced by the persistence of the sound after its source has ceased emitting. When the reverberation in the space in which the initial sound is being picked up is sufficient to cause one sound to hang over and become mingled with succeeding sounds, in other words, so that the sound from one syllable interferes with that of the succeeding syllable, it is practically impossible to improve the acoustic conditions solely by the use of the public address system. In such a case, the first procedure is to place material which absorbs sound in the space. The purpose of this absorbing material is to lower the time required for the sound to die away after the source ceases to emit. The amount which any given material lowers the time of reverberation depends not only upon the amount of material introduced, but also upon its disposition within the space.

The term "echo" applies to a similar phenomenon, but is generally used where there is sufficient time lag between the reflected sound and that originally emitted, so that two distinct impressions reach the ear.[1]

The troubles encountered from echoes usually occur only in large buildings or large open spaces surrounded by buildings, trees, or other obstacles and are generally associated with interferences with the reproduced sound rather than with the original sound. There are cases, however, particularly in auditoriums, where some of the walls or ceiling are large curved surfaces, in which case localized echoes may result. The speaker's voice or extraneous sounds from the audience may be reflected from one or more of these surfaces to focus spots where the volume of sound is consequently abnormally great. It is important, therefore, that the transmitter which is picking up the sound shall not be located at one of these spots. These points of localized echo are particularly troublesome also when they occur in the space occupied by the audience. Under these conditions not only is the sound intensity too great, but the character of the sound is altered and very often badly confused. The avoidance of such difficulties is a matter of test and the proper arrangement of the reproducing mechanism, as will be seen later in some detail.

The effect of resonance seldom occurs in connection with the amplified and reproduced sound, inasmuch as the spaces dealt with are large and their natural frequencies are too low to be troublesome. Resonance usually becomes of importance in connection with mounting the pick-up apparatus or transmitter. It generally results from attempts to conceal the transmitter by placing it in some form of small enclosure. The best form of housing from an acoustic standpoint consists of a screen cover which protects the instrument from being struck or injured but in no way affects the sound reaching it.

Resonance produces a distortion which it has been customary to consider as of two varieties. First, there is an unequal amplification of sounds of various frequencies and second, there is the introduction of transients. These transients occur whenever the sound changes but are most easily recognized audibly by their continuation after the source has ceased emitting. They also have frequency characteristics which depend not only on the sound which started them but also upon the character of the resonant portion of the system.

The troubles introduced by diffraction are seldom of

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 14-17, 1923.

1. Collected Papers on Acoustics, Wallace Clement Sabine, *Harvard University Press*, 1922.

very great importance except where the sound is reflected from regularly spaced reflectors or passed through regularly spaced openings. Quite serious diffraction troubles have been encountered when operating a loud speaker in a large field, surrounded by an open work board fence, the trouble being evidenced by very distinct areas, particularly at the outskirts of the audience where the sounds were badly distorted.

The difficulties encountered as a result of "singing" form one of the most troublesome problems connected with the actual operation of these systems. When a portion of the sound emitted by the projectors reaches the transmitter with sufficient intensity, that its reproduction is as great as the originally emitted sound from the projectors, and with such phase relation that it tends to aid the original sound, the system will emit a continuous note. Moreover, when the portion of the sound from the projectors which reaches the transmitter is not sufficient to cause a continuous note, it may be sufficient to cause considerable distortion of the speech or music. In excessively reverberant halls these conditions are often fulfilled when the actual amplification is so small that the people at the distant points are scarcely able to hear the speaker. In all cases in our experience the difficulty has been sufficiently overcome by properly placing the transmitter with respect to the projectors. The situation is very much helped by the presence of the audience, which adds considerably to the acoustic damping of the room.

It will be seen, therefore, that the acoustic conditions of the space in which loud speakers are used are of considerable importance.

Characteristics of the System

The first requirement of the system itself is that it shall reproduce speech or music faithfully. A system is said to do this, or in other words, its quality is called perfect, when the reproduced sound contains all of the frequencies, but no others, contained in the original sound striking the "pick-up" mechanism, and when these frequencies have the same relative intensities that they had in the original.

An imperfect or distorting system is one which fails to fulfill this requirement. There are two main types of distortion which had to be considered; the first being the unequal amplification of the system for the various frequencies constituting the sound and the second being the introduction of frequencies not present in the original sound. For simplicity of discussion, this last class will be divided in three parts, namely: the effect of transients, the effect of asymmetric distortion and the effect of disturbing noises.

The effect of transients has already been mentioned in connection with acoustics and they, of course, produce the same type of distortion whether they occur in the acoustic or the electrical system. Transients occur whenever the sound changes either in pitch or intensity, and are introduced at the beginning and ending of each speech sound. This modification of the characteristics of the speech sounds acts to lower the intelligibility. It probably causes more trouble in speech transmission than the fact that the sound continues after the source ceases.

Asymmetric distortion affects one half of the wave differently from its other half. This causes the introduction of frequencies which, in some cases, produce very serious disrurbances in the transmission of music and speech. The most noticeable troubles are from the formation of sum and difference tones.[2] Such tones are likely to give rise to dissonances with the other sounds occurring in the music. In the case of speech asymmetric distortion manifests itself by a lower intelligibility.

The effect of foreign noises sometimes encountered is twofold. First, they influence the ability of the listener to hear the characteristic speech sounds and hence tend to lower the intelligibility. Secondly, the constant attempt of the hearer to sort out the speech sounds or music through the disturbing noises tires him appreciably. In order that this strain shall be inappreciable, it is desirable that the sound delivered by the system shall be at a power level at least 10,000 times that of the noise.

The second general requirement which is placed on a successful system is that it shall deliver its faithful reproduction loud enough for all the audience to hear it comfortably and enough above noise for good intelligibility. In this connection there have arisen one or two interesting points bearing on the psychology of hearing. One of the most striking of these is concerned with the coordination between hearing and seeing. Although the projectors are usually mounted twenty or more feet above the speaker's head, and in some exceptional cases, slightly to one side of him, the majority of the audience is conscious of only one source of sound, and that appears to be the speaker himself.

This phenomenon is so marked that in several cases the question has been raised in the minds of the listeners as to whether the system was functioning. They could only be convinced that it was by having it shut down for a few seconds when their inability to hear made them realize how successfully the system could operate.

Another of these psychological phenomena deals with the apparent distortion of the voice when its intensity at the ears of the listener is too great or too small. If the speaker is talking in a normal conversational tone, his voice contains a larger percentage of low frequencies than is the case when he is raising his voice to a considerable volume. If the loud speaker so amplifies this voice that it reaches the audience with such volume that their instinct tells them that the speaker should be shouting, the system appears to make his voice sound quite heavy and somewhat

2. Origin of Combination Tones in Microphone-Telephone Circuits. E. Waetzmann, *Annalen der Physik*, Vol. 42, 1913.

unnatural. It has been found necessary, therefore, to so regulate the amount of amplification that the people at the furthest portion of the hall can hear comfortably and the volume of sound should not be permitted to become any louder than necessary to meet this condition. On the other hand, if the volume is insufficiently loud, certain of the weaker speech sounds are entirely lost, and it becomes difficult to understand.[3]

Solution of the Problem

With these considerations in mind it may be interesting to take a brief survey of the whole problem and the method by which the solution was reached. Two general methods of attack were considered. The first was to attempt to make each unit of the system faithfully reproduce its input, while the second was to make any distortions of one part of the system, cancel those of another portion, so that the complete system would operate satisfactorily. In either case, it was desirable to keep each unit free from asymmetric distortion, as this type of distortion cannot be easily compensated for.

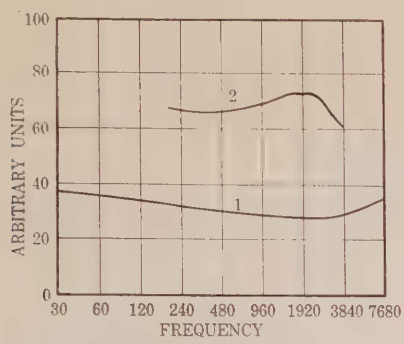

Fig. 1—1-Condenser Transmitter with Associated Amplifier
2-Carbon Transmitter without Amplifier

While it would probably have been simpler to follow the second line of attack, the greatly increased flexibility of a system in which each part is correct in itself was of sufficient value to cause the attempt to be made that way. When it is realized that these systems, to be commercially successful, must be capable of operating for various sized audiences, ranging possibly from one thousand to several hundred thousand, that they must be used in connection with long distance telephone lines, as well as with either radio broadcasting or receiving stations, the desire for flexibility can be understood.[4]

As a result of attempting the development in the manner already described, there has resulted a system which involves four functional units; a "pick-up" mechanism or transmitter unit, a preliminary amplifier unit, commonly called the speech input equipment, a second amplifier unit commonly called the power amplifier, and a receiver-projector unit for transforming the amplified currents back into sound, and properly distributing it throughout the space to be covered.

It may be interesting at this place to determine how successfully these various units and the system as a whole fulfill the requirements of equal sensitivity to all frequencies within the important speech or music range. Fig. 1 shows the relative sensitiveness of the transmitter as a function of frequency. The ordinates are proportional to the logarithm of the power delivered for constant sound pressure at the diaphragm and the abscissa to the logarithm of the frequencies employed. The lower of the two figures refers to the condenser transmitter with its associated input amplifier.[5] The upper refers to the push-pull carbon-type transmitter. These transmitters will be described in detail later.

Fig. 2 shows a similar curve for the complete amplifier system, comprising a three-stage speech input amplifier, and a power stage capable of delivering approximately 40 watts of speech frequency electrical power without distortion. In connection with these amplifiers a sharp distinction should be made between their gain rating, or amplification, and their overload or power rating. Gain measures the power amplification which can be obtained provided the input is small enough so that the equipment at the output end is not overloaded. Overload or power rating refers to the maximum power which can be supplied by the amplifier without causing distortion of the currents being amplified. Although the power rating of power equipment is usually determined by the heat which can be dissipated, a marked distortion of wave form takes place when the iron in any of the apparatus is worked beyond the straight line portion of the magnetization curve. In the case of amplifiers, the maximum power obtainable is limited by the power output at which distortion occurs rather than by the heat which can be dissipated.

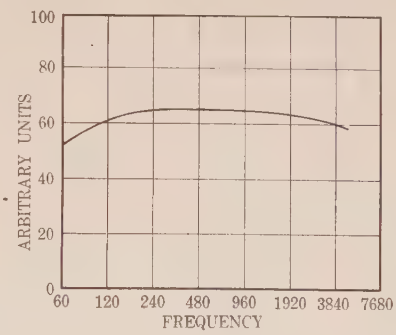

Fig. 2—Public Address System Amplifiers

Fig. 3 shows a chart for the characteristics of the complete system, including the carbon transmitter, the speech input and power amplifiers and the receiver projector unit.

In connection with the requirements for equal

3. Physical Examination of Hearing R. L. Wegel, *Proceedings of the National Academy of Sciences*, Volume 8, Number 7, July 1922.

4. Use of Public Address Systems with Telephone Lines, W. H. Martin and A. B. Clark. Presented before A. I. E. E. Feb. 14, 1923.

5. The Sensitivity and Precision of the Electrostatic Transmitter for Measurement of Sound Intensities. E. C. Wente, *Physical Review*, N. S. Vol. 19, No. 5, May 1922.

amplification of all frequencies, it is interesting to note that a system, which does not fail to reproduce equally all frequencies in the speech range by more than a ratio of 10 to 1 in reproduced power, is indistinguishable, from a perfect system or from the speaker, himself. It seems probable that this effect is, in some way, connected with variations in the frequency sensitiveness curve of normal ears. Normal ears show a sensitiveness variation with frequency as great as 10 to 1 and the frequencies of maximum sensitiveness vary materially from one individual to another.[6]

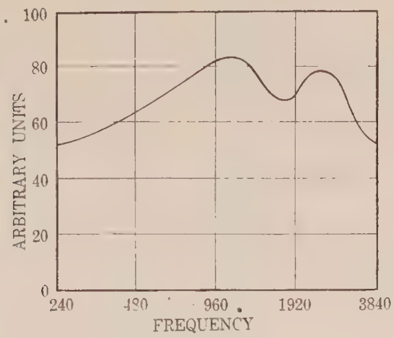

Fig. 3—Complete Public Address System with Carbon Transmitter

It has been found that in order to transmit speech with entire satisfaction for loud speaker purposes, that is, sufficiently well so that the audience is not aware of the contribution of the mechanical equipment, it is necessary for the system to operate with essentially uniform amplification over a range of frequencies from 200 to 4000 cycles. While there are, in speech, frequencies slightly outside of this range, the loss in naturalness and intelligibility by the system's failure to reproduce them, is slight.[7]

While no such frequency range is required for intelligibility only, it has been found that systems not covering substantially this frequency range, sound unnatural. When the lower frequencies are missing, the reproduction sounds "tinny." When the higher frequencies are missing it sounds heavy and muffled. The requirements for thoroughly natural reproduction of music are probably more severe, particularly in the low-frequency region, than are the similar requirements for speech, but, at the present time, complete data are not available to indicate the contribution of these frequencies to naturalness.

In connection with the flexibility of the system, it is interesting to note that the speech input equipment has been designed to raise the power delivered by the transmitter to such an extent that it is sufficient for long distance telephone transmission or for the operation of a radio transmitting set. The power amplifier is designed to receive power at approximately this level and deliver it to the projector units sufficiently amplified to operate them satisfactorily.

Future Development

In viewing the loud speaker field from the point of view of future development there are two lines of attack along which work is being done, and which give promise of success. These are the improvements in frequency characteristics and increase in the range of loudness which the system can accommodate satisfactorily.

The improvement to be expected from a more uniform frequency characteristic is mainly an increase in naturalness, especially where music is being reproduced. A slight increase in intelligibility may be hoped for, although this factor is of little importance, as the present system is satisfactory in this respect.

The other improvement mentioned, namely, the volume range, is probably the more difficult, but is necessary before music can be reproduced in a perfect manner. Rough experimental data indicate that the loudness in an orchestra selection may vary from one part of the selection to another by a ratio as great as 50,000 to 1. While the present equipment does not operate with entire satisfaction over this range of loudness, it has been found relatively easy to obtain good results by manual adjustment of the amplification during the rendering of the selection. If the gain is varied in small enough steps, the change is not noticeable to the listeners.

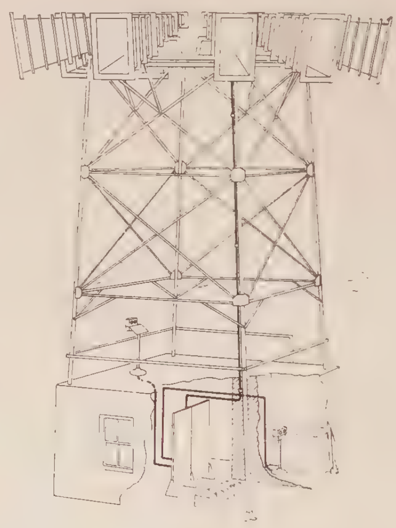

Fig. 4

An increase in the loudness range would render the manual adjustment unnecessary and would make the reproduction a faithful duplicate of the music as actually played.

Technical Description of the System

The foregoing discussion having described the requirements which must be met in order that the public address

6. Frequency Sensitiveness of Normal Ears, by H. Fletcher and R. L. Wegel, *Physical Review*, July 1922.

7. The Nature of Speech and its Interpretation. Harvey Fletcher, *Journal of the Franklin Institute*, Vol. 193, No. 6, June 1922.

system shall successfully transmit speech and music, the system in its commercial form will now be described. In order to make clear the arrangement of the equipment, a typical installation is shown in Fig. 4, this being an installation where the audience and speaker are in the open air, and where no connection is made with the long distance lines. It might be well to state here that with the equipment shown an audience of 700,000 can be adequately covered.

Some of the sound leaving the speaker's mouth is picked up by the transmitter, on a reading-desk type of pedestal, which is normally mounted at the front of the platform.

Fig. 5

The feeble currents from this transmitter are led by carefully shielded leads to the amplifiers in the control room, which is usually located directly beneath or to one side of the speaker's stand. A floor space of not more than 125 square feet is required for this room, even in the case where it is desirable to transmit phonograph music to the audience between speeches.

The amplifier and power supply equipment is shown on the two panels in the center of the control room. The amplified speech currents are led from these amplifiers to the receiver projector units, which, in this case, are arranged on the super-structure above the speaker's platform. This position is most desirable, as the illusion produced is such that the voice appears to come from the speaker rather than from the projectors, a factor, the importance of which has already been mentioned. Moreover in this position the acoustic coupling between the transmitter and the projector is a minimum, permitting the operation of the system at a satisfactory degree of amplification with an ample margin below the point where singing troubles are encountered.

A public address equipment, similar to that just described, but with a somewhat lower power output, has been developed for use at the smaller open air meetings, and in all but the largest indoor auditoriums. Fig. No. 5 shows one of these equipments, mounted on an automobile truck, which has been employed at a number of points in the eastern part of the United States. This smaller system has characteristics equally as good as the larger system in regard to faithful reproduction of speech and music, with a power output in the order of one-tenth as great. An audience of 50,000 can be adequately covered at an outdoor meeting with this system.

Fig. No. 6 is a schematic arrangement of the equipment at an installation of the type shown in Fig. 4. At the extreme left are the transmitters where the sound waves are picked up. The output from these transmitters is taken to a switching panel where means are provided for cutting in the various transmitters. From this panel the transmitter currents are taken to the transmitter amplifier, which is capable of amplifying them to a power level suitable for input to the power amplifier, or for connection to the long distance lines, in those cases where the speeches are transmitted to distant audiences. It is also suitable where connection is to be made to a radio station for broadcasting the speeches. The power amplifier is shown just to the right of the transmitter amplifier. Below it is indicated the power supply equipment by which the commercial power is converted to a form suitable for the vacuum tubes in both amplifiers. The output from the power amplifier is taken through a panel where switches and a multi-step auto-transformer are provided for the regulation of several projector circuits. Just above this panel is an indicating instrument, known as the volume indicator, provided in order that the operator may know what volume output is being delivered to the projectors.

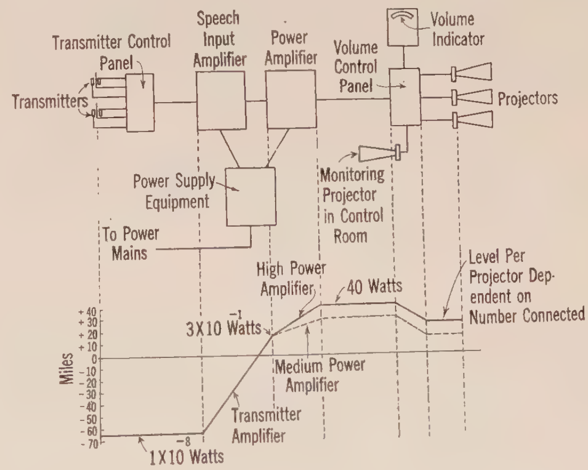

Fig. 6

The projectors, at the extreme right of the figure, consist of the motor or receiver unit transforming the speech currents into sound waves, and a horn to provide the proper distribution of the sound.

It is interesting to note the power amplification which is obtained in the larger of the two systems from the transmitter to the projectors. Referring to Fig. No. 6, a chart will be seen which indicates the power levels through the system drawn to a scale based on miles of standard telephone cable, our usual reference unit. The output of the high quality transmitter is

of the order of 65 miles below zero level, this latter being the output from a standard telephone set connected to a common battery central office by a line of zero resistance. Expressed in watts the output of this transmitter under average conditions of use with the public address system is of the order of 10^{-8} watts. Incidentally, this is of the same order as the speech power picked up by the transmitter, or in other words, the transmitter does not amplify the speech power received by it as is the case with the transmitter used for regular telephone service.

This very minute amount of power in passing through the transmitter amplifier may be amplified about 120,000,000 times. Expressed in terms of telephone power levels, this is 17 miles above the zero level previously mentioned, or a few tenths of a watt.

The power amplifier serves to increase this power from a level of 17 miles to about 40 miles, the latter corresponding to about 40 watts. This power is then distributed to the projectors, the amount consumed by each projector, of course, depending upon the number connected.

An idea of what this amount of power at speech frequencies means may be given by the statement that it is sufficient to operate at a volume level slightly above that considered commercial all of the 12,000,000 telephone receivers in use in the Bell system if these were directly connected to the amplifier.

In describing the various pieces of equipment which together make up the system, we will follow the order in which the power is carried through the system from the transmitter to the receiver-projector units where the amplified sound waves are propagated.

Transmitters

In the early work on the public address system, an air-damped, stretched diaphragm condenser transmitter was employed, having a thin steel diaphragm about 2¼ inches in diameter, constituting one plate of the condenser. The other plate was a rigid disk, the dielectric being an air film 1/1000 of an inch in thickness. Due to the stretching of the diaphragm and the stiffness of the air film, the diaphragm of this transmitter had a natural period of approximately 8000 cycles per second which is well above the important frequencies in the voice range. This high natural period, in conjunction with the damping due to the thin film of air, resulted in a transmitter of very high quality of reproduction. However, its extremely small capacity (in the order of 400 micro-microfarads) made it necessary to use leads of very low capacity between the transmitter and the first amplifier, and due to the high impedance of the transmitter and its associated input circuit to voice frequency currents, these leads were very susceptible to electrostatic and electromagnetic induction. It was necessary to limit them to a length of 25 feet, and to provide complete shielding. Moreover the output of this transmitter was less than one five-thousandth of that of the transmitter now used, and for the early installations of the system, it was necessary to provide a preliminary amplifier beneath or to one side of the speaker's stand in order to keep the transmitter leads short and to provide sufficient power to properly operate the main amplifiers. Work was therefore undertaken to provide a transmitter, having quality practically as good as the condenser transmitter, volume output sufficient to operate the main amplifiers, and not requiring the elaborate precautions as to shielding the leads.

The high quality transmitter which was the result of this development work is of the granular carbon type with two variable resistance elements, one on each side of the diaphragm and is commonly known as a push-pull transmitter. It has nearly the same high quality reproduction characteristics as the condenser transmitter, due to the use of the same stretched diaphragm and air damping structure. It introduces no appreciable distortion over the range of frequencies required for good reproduction of speech, but it must be understood, that this quality was obtained only at

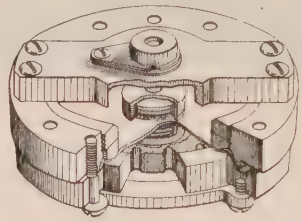

Fig. 7

the sacrifice of sensitiveness, the latter being in the order of 1/1000th that of the transmitter used at telephone stations in the Bell system. With the multi-stage vacuum tube amplifiers available this low volume efficiency is not serious and in fact we are using this transmitter for what is known as distant talking, *i. e.*, the speaker may be at a distance of five or six feet from the transmitter. This is, of course, necessary in any transmitter suitable for public address work as it is not possible to greatly limit the movement of the speakers, nor can they be required to use a hand transmitter. It might be well to point out that this sacrifice in volume efficiency in order to gain high quality is possible at the transmitting end of the system, but not at the opposite end where the electrical power is transformed into sound waves and propagated, as the device at this point must be capable of handling large amounts of power with minimum distortion.

Referring to Fig. No. 7 which is a cut-away view of this push-pull high quality carbon transmitter, the granular carbon chambers will be seen. The electrical path through each of these variable resistance elements is from the rear carbon electrode through the carbon granules to a gold-plated area on the diaphragm itself. The resistance of this path is about 100 ohms and as the two buttons are in series for the telephone

currents, the transmitter is designed to work into an impedance of 200 ohms. The double button construction almost completely eliminates the distortion caused by the non-linear nature of the pressure-resistance characteristics of granular carbon.

As this instrument has a practically flat frequency characteristic no collecting horn or mouth piece is used with it as resonance is introduced by such chambers, with accompanying distortion. To insure the insulation of the transmitter from building vibrations, a simple spring suspension has been provided. To protect the transmitter from injury, two types of transmitter mountings have been used, both arranged for the suspension of the transmitter in a screen-enclosed space—the first adapted to take a single transmitter for indoor use only, while the second for outdoor use, mounts two transmitters within a double screen enclosure to prevent any noise effects due to winds. This second type is arranged to attach to a simple pedestal-type of reading desk, which it has been found desirable to provide as there is a slight tendency for the speaker to remain fairly close to the desk. In this connection it is interesting to note that we have found a small rug, so placed as to cover the area which the speaker should occupy during the delivery of his speech, is of great assistance in this regard, as he unconsciously confines himself to the area of this rug. Both of these measures to insure the speaker remaining in proper relation to the transmitter, are supplemented, wherever possible, by an explanation of the system to all the speakers previous to the actual performance.

Transmitter Switching Panel

Resuming the path of the speech currents through the system, the output from the transmitters is taken to a panel designed to enable the operator to switch quickly from one transmitter to another, as with some public functions, the speeches are made at different points during the ceremonies. This switch is arranged to short-circuit the output of the power amplifier when passing from one transmitter to another, to prevent clicks in the projectors. In certain cases, the equipment is arranged to permit two or more transmitters to be connected to the amplifiers at one time, as is desirable when solo singers and an orchestra are to be picked up in a theatre, with proper adjustment of their respective volumes.

The amplifier equipment has been built in four units which may be grouped as necessary under the various conditions encountered in commercial installations. The proper amplifiers are determined, first, by the source of the voice frequency current to be amplified, that is whether a distant talking or a close talking transmitter is to be used, or whether the speeches are brought in over a telephone line, and secondly, the size of the space in which the amplified sounds are to be delivered to the audience. It was found that four units would provide for all the conditions occurring in practise, two of these being speech input or transmitter amplifiers with different gains and two being power amplifiers of different power ratings. These units and other equipment used with the system, are made up in panels, of uniform width, in order that the proper equipment for any installation may be assembled on two vertical angle iron racks arranged to be fastened to the control room floor.

Speech Input Amplifier—First Type

The first of the speech input amplifiers is shown schematically in the upper part of Fig. 8. It is a three-stage amplifier. Two potentiometers provide adjustment of the gain over a large range, and switching arrangements allow the output to be connected directly to the input of the power amplifier, when the program is to be transmitted to a local audience; or to be connected, through a transformer of proper impedance, to

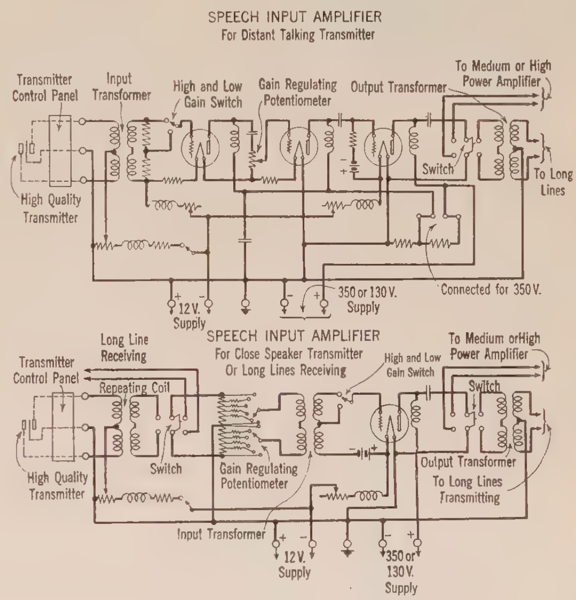

Fig. 8

the long distance lines when the program is to be transmitted to a distant audience, or to a radio-broadcasting station. The filaments of the tubes are supplied from a 12-volt storage battery, while the plate circuits obtain direct current at 350 volts from the power supply equipment mentioned later. Arrangements are also provided for using 130 volts instead of 350 volts under certain conditions. The proper grid potentials are obtained by utilizing the drop over a resistance in the filament circuits of the first two tubes, and for the third tube small dry cells furnish the grid potential. The maximum gain with this amplifier is 85 miles, which expressed as a power ratio is 1.2 x 10^8. The maximum power output is approximately 3/10 of a watt. The front and rear views of this amplifier, mounted on the supporting rack, are shown in Fig. 13, where the gain regulating potentiometer, the rheostats for controlling the filament and transmitter currents, the three tube mountings

with protective gratings and the jacks which permit the connection of instruments for determining the current flow in the filament plate and transmitter circuits, will be noted. Great care was taken in the design of this amplifier to obtain as nearly as possible equal amplification of all frequencies in the important voice range. The transformers, and the retardation coils in the plate circuits were chosen with this consideration in mind.

Power Amplifiers

For practically all of the larger installations the maximum power possible with the system is required and the output from the transmitter-amplifier is taken directly to the high power amplifier. Referring to Fig. 9 it will be seen that this is a four-tube amplifier so connected that but one stage of amplification is obtained.

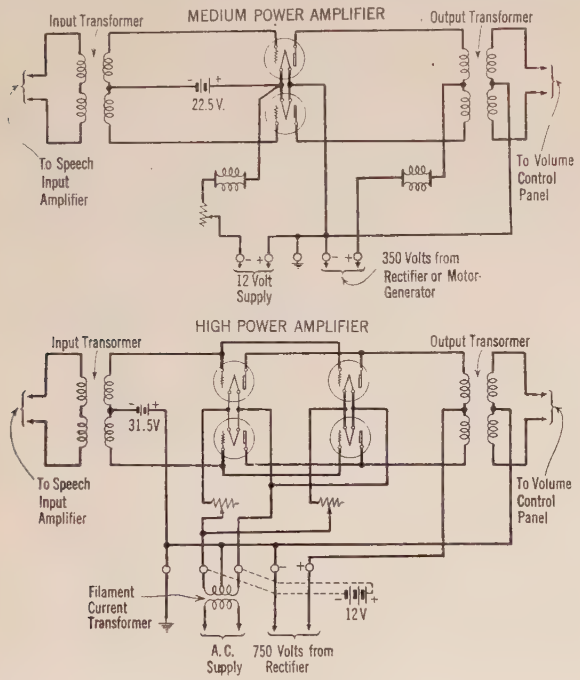

Fig. 9

Usually alternating current at 12 to 14 volts is used for heating the filaments of these tubes, the latter being connected in what we know as a push-pull arrangement. It will be seen that each side of the push-pull arrangement consists of two power tubes in multiple. It is interesting to note that this push-pull arrangement of the tubes will deliver somewhat more power for equal quality than the same number of tubes connected in the ordinary multiple arrangement, as the tubes may be worked beyond the straight part of their characteristic. The grid potential is chosen to permit the largest variation of current without distortion and is obtained from a group of small flashlight batteries.

The output transformer at the right of the figure is designed to match accurately the impedance of the tubes to that of the number of receiver-projector units which has been found to give the greatest flexibility under the varying conditions of commercial operation. This amplifier, speaking in telephone terms is worked at a gain of 23 miles, a power amplification ratio of about 200. Its maximum power output is about 40 watts. The plate circuits of the tubes are supplied at a d-c. potential of 750 volts. As has been pointed out previously, this amplifier gives a practically uniform gain for all the important frequencies in the voice range. This high-power amplifier is shown mounted on the supporting rack, in Fig. 13. The apparatus on the rear of the panel is protected with a sheet metal cover and integral with this cover is a disconnecting switch, which, when the cover is removed, cuts off the high potential from all the exposed parts on the set.

For indoor installations where the audience is small the power output given by the high-power amplifier is not required and a medium-power amplifier has been developed for this use. It is arranged to connect directly to the transmitter amplifier and the output is taken to the projectors through the volume control panel. It is worked at a gain of 17 miles or a power amplification ratio of about 33. The maximum output is about 4 watts, or about one-tenth of the power obtainable from the high-power amplifier.

The schematic of this amplifier, is shown in Fig. 9. The input coil is the same as is used in the high-power amplifier. The push-pull connection of the tubes is also used in this amplifier, although but two power tubes are used. The filaments of these tubes are supplied from a 12-volt storage battery while the plate circuits are supplied at 350 volts direct current from a motor generator set which will be described later.

Speech Input Amplifier—Second Type

A speaker using the system may read his speech from his home or office and in such cases it is unnecessary to use the push-pull carbon transmitter in the distant-talking manner. For use when this transmitter is spoken into from a distance of a few inches, a second form of speech input amplifier has been made available having a gain of the proper value to supply either of the power amplifiers, or a long distance line if desired. This gain is relatively small as the output of the transmitter when used for close talking is about 10,000 times that when it is used for distant talking.

Fig. 8 shows the schematic of this amplifier which is a single-stage one, employing one tube and having the same over-load characteristic as the first form of speech-input amplifier. A two-way switch permits the connection of the transmitter or an incoming long distance line to the amplifier. To the right of this switch is a potentiometer for regulation of the gain. To the right of the tube is a second two-way switch for connecting the output either to the power amplifier or through an output transformer to an outgoing long distance line. The power supply for the tubes and transmitters, is the same as was described under the first form of speech input amplifier.

The switching means provided on this amplifier allow it to be used in a number of ways. Announcements from a close talking transmitter may be made from the projectors through a power amplifier or may be sent out on the telephone lines to a distant public address system installation or a radio-broadcasting station. In addition to these uses, incoming speech over the long distance lines may be put out on the projectors through the power amplifier or may be sent out on the long distance lines to a distant installation.

Volume Control

As discussed heretofore, it is necessary to give the operator control of the volume put out by each projector or group of projectors. The equipment provided for this purpose is mounted on a panel uniform with the others and consists essentially of an auto-transformer connected across the output of the power amplifier with 11 taps multipled to the contacts of eight dial switches, the arrangement being shown schematically in Fig. 10. Seven of the dials control projector circuits on each of which one or more projectors may be grouped, the eighth dial being reserved for controlling the volume of

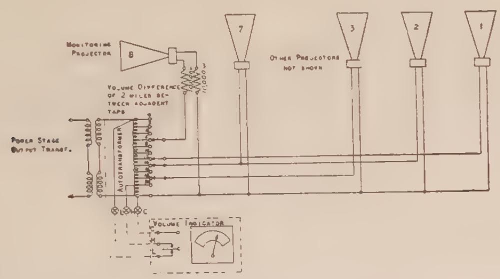

Fig. 10

the operator's monitoring projector in the control room. A key is associated with each dial for opening the circuit and a master key is provided for cutting off all of the projectors simultaneously.

The device shown as "Volume Indicator" in this figure consists of a vacuum tube detector bridged across the output terminals of the power amplifier. The rectified current is taken to a sensitive direct-current meter of the moving coil type, the degree of deflection of this meter measuring the output from the power amplifier when connected at a proper place in the circuit. The deflections of the meter therefore serve as a basis for determining the adjustment required on the transmitter-amplifier to give the required output when switching from one transmitter to another or for different speakers.

Receiver—Projectors

From the control panel the power is taken to the projectors, each of these consisting of a loud-speaking receiver mechanism to transform the speech-currents into sound waves, and a horn to distribute the sound. The receiver is so designed that it will carry several watts with small distortion. It is shown in Fig. 11 where it will be seen that a light spring-supported iron armature is mounted between the poles of a permanent magnet and passes through the center of the coils carrying the voice currents. A light connecting link ties one end of this armature to the diaphragm which is of impregnated cloth, corrugated to permit vibrations of large amplitude. A stamped metal cover protects the parts from mechanical injury, and a cast iron case, in which the whole assembly mounts, is provided for protection against moisture.

One of these receivers equipped with the largest projector provided, will carry without serious distortion

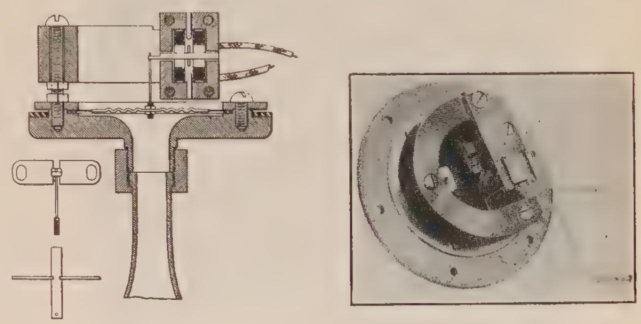

Fig. 11

or overheating, power which is about 27 miles above the zero level. With this output, it is possible to project speech a distance of 1000 feet under ordinary weather conditions and this has been done at several installations.

On account of the different conditions encountered in installations three types of horns have been used, shown in Fig. 12. Where it is necessary to project the sound to great distances, a tapering wooden horn is used, of rectangular cross section, 10-1/2 feet long, the

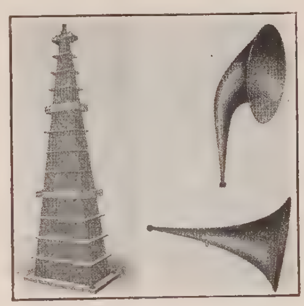

Fig. 12

walls being stiffened to prevent lateral vibration. For most installations these large horns are not required, and two types of fibre horns are used. One of these is straight in the body, with a flaring open end, while the other used in the control room, is bent.

The grouping of projector units on the volume control switches differs with the type of installation. In outdoor performances, the necessity of correcting the volume in certain directions due to varying winds makes it advisable to group adjacent projectors on a single switch. This is not the case with indoor per-

formances, as no wind effects are possible. Instead, symmetrically placed projectors which will always require equal volume are grouped on a single switch.

Power Supply Equipment

In order to convert the commercial electric power supply to forms suitable for supplying the filament and plate current for the vacuum tubes in the amplifiers, two types of power equipment have been made available. When the installation is of a size requiring the high-power amplifier, a vacuum tube rectifier taking its supply at 110 or 220 volts, 60 cycles, and delivering 750 volts direct current for the plate circuits is employed. A potentiometer arrangement provides a direct-current supply at 350 volts for the speech-input amplifier tubes. Full wave rectification is obtained and a filter consisting of a large series reactance coil and bridged condensers is used to render the direct-current output suitable for this use. Included in the power equipment is a step-down transformer for supplying the filament of the power amplifier. For the larger installations, employing the rectifier, the total power drawn from the commercial supply is 1500 watts.

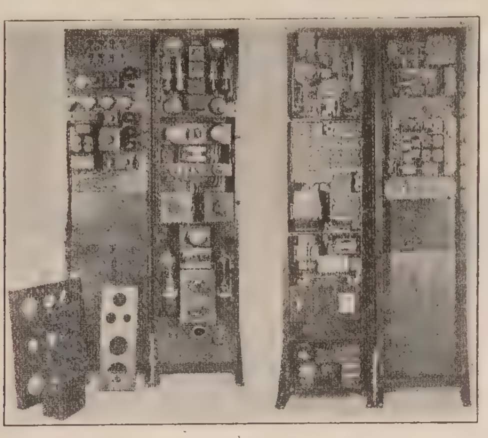

Fig. 13

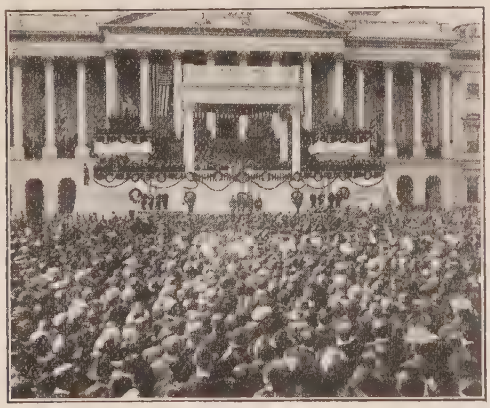

Fig. 14a

For installations of a size not requiring the use of the high-power amplifier, a compact motor generator set is provided consisting of a 350-volt d-c. generator driven by a suitable motor, the total power drawn from the supply mains being about 600 watts. A low-voltage generator for supplying direct current at 12 volts for the operation of the amplifier tubes is incorporated in this motor generator set. A filter is necessary and a reactance coil and a 12-volt storage battery is floated across its output. This supplies the transmitters and the tube filaments. The necessary indicating neters are provided on a meter panel for observing the voltages and currents of all the items of equipment which do not have individual meters associated with them.

Fig. 14b

Observing System

In addition to the monitoring projector provided in the control room for the guidance of the operator, it has been found necessary in all but the simplest installations to provide observing stations at various points in the audience. The observers stationed at these points are equipped with portable telephone sets, by which they may immediately communicate with the operator, who is provided with a telephone set consisting of a head receiver and a breast transmitter. The value of these observation stations for regulation of output volume during a program will be apparent.

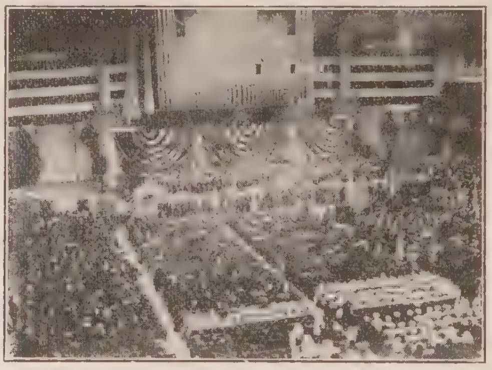

Fig. 15

In the case of an open air performance a variable wind may make it necessary to increase the volume of

certain projectors and decrease the volume of others in order to cover the audience uniformly. Without the observers, the control operator would be unable to take care of these changes.

Considerable preparation is required where the equipment is being used for the first time, in order that the performance of the public address system installation will be of the highest order. Where the acoustic conditions are unfavorable it is necessary to make tests with various arrangements of the projectors, in order to determine the most satisfactory one. It has been found advisable to carry out the entire program previous to the performance in order that the operating force may become familiar with the sequence.

Fig. 16a

Conclusion

The usefulness of such systems is very well illustrated by a few of the results which have actually been obtained. Fig. 14 shows a crowd of approximately 125,000 people, every one of whom was able to hear clearly and distinctly all of the words spoken in President Harding's inaugural address in March 1921. This crowd was relatively small, compared with the crowd which could be accommodated by one of the larger type systems. Some insight into the number of people which could be accommodated can be gained from the fact that such a system will cover comfortably a complete circle whose diameter is 2000 feet when the projector units are placed at the center.

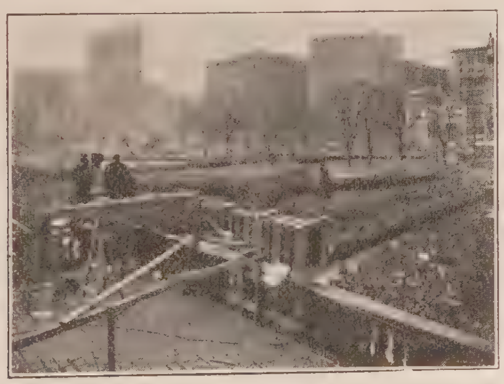

Fig. 16b

One of the largest and most successful uses to which this equipment has been put took place on Armistice Day in 1921 when 20,000 people in San Francisco, 35,000 people at Madison Square Garden, New York City, and approximately 100,000 people at Arlington Cemetery near Washington joined in the impressive ceremonies which took place at the burial of the Unknown Soldier. Figs. 15, 16 and 17 are views at the three cities, during the ceremonies.

Fig. 17a

Some of the other uses which have been made of the public address system are the Republican and Democratic Conventions prior to the last presidential election, after-dinner speaking in large ballrooms and in halls where speakers have to address large audiences.

Fig. 17b

There is one more application of this type of equipment which is gaining rapidly in its use. This last is the application of the speech input equipment to radio broadcasting. The broadcasting of the opera, Aida, from the Kingsbridge Armory, and of the Philharmonic Concerts from the Great Hall of the College of the City of New York are two of the successful uses where music

and speech were concered, while broadcasting of the results of the football games from the various distant cities indicate possibilities for the dissemination of interesting information[8].

The social and economic possibilities of the system are scarcely realized by the public as a whole at the present time, when the method resorted to for reaching large numbers of people is usually the printed word. While this method is effective, it leaves much to be desired in that the personal touch between the man with ideas and the people to receive them is entirely lost. The difficulty for any but those possessing the strongest voices to reach an appreciable number of people at one time has led to a decline in oratory as a means of conveying public messages to large numbers, for it is not always the man with the best ideas or the best ability of presenting them, who is blessed with a powerful voice. A system such as the one which has just been described enables the speaker, even though his voice be relatively weak, to address at one time and in one gathering, several hundred thousand persons, and if the system be used in connection with long distance telephone lines or radio broadcasting, the number which may be reached is increased almost indefinitely. The value of such a situation can hardly be overrated in times of national emergency or stress, when it is necessary for those in responsible positions in the Government to get their message to the people directly.

The development of the apparatus just described has been the result of the efforts of such a large number of investigators working cooperatively that no attempt has been made to acknowledge the individual contributions.

CONFERENCE OF ENGINEERS OF STATE UTILITY COMMISSIONS

For more than ten years the Bureau of Standards has been giving active study to various problems connected with the operation and regulation of public utility services. This work has been done in cooperation with utility companies as well as city and state officials who are concerned with these problems. Since the practise of exercising control of utilities through state commissions has spread rapidly, the Bureau's relations with such commissions have become more and more important. While these relations have been very cordial and mutually helpful, it has been considered desirable to arrange for some more formal method of contact with engineers of the commissions.

In connection with a meeting of the Sectional Committee which is revising the National Electrical Safety Code, representatives from seven state commissions visited the Bureau in December 1922, and an informal meeting was held to consider the best method of procedure for a larger conference. In accordance with decisions then reached, arrangements were completed for a general conference of engineers on March 2 and 3 at the Department of Commerce and the Bureau of Standards. More than thirty engineers, representing various state commissions, attended this conference. The Bureau believes that this opportunity for discussion between engineers from the various states will be of material assistance to them in meeting problems which are more or less common to all.

The program for the conference was confined strictly to engineering problems. A number of commission engineers presented papers on matters in which they have had special experience. These included the "Grading of Public Utilities," which was discussed by Mr. C. B. Hayden, Assistant Engineer of the Wisconsin Railroad Commission, and Mr. J. Howard Mathews, Service Engineer, Illinois Commerce Commission; "The Public Interest in Heating Value Standards for Gas" on which Mr. S. A. Covell, Gas Engineer of the Maryland Public Service Commission, and Mr. C. R. Vanneman, Chief Engineer, New York Public Service Commission spoke; and the "Conservation of Natural Gas" discussed by Mr. James Imboden, Chief Engineer of the West Virginia Public Service Commission, and Mr. L. G. White, Chief Engineer of the Ohio Public Service Commission.

There was also a general discussion on the "Grounding of Electrical Circuits" with an introduction by M. G. Lloyd, Electrical Engineer of the Bureau, and on the problem of "Inductive Interference" introduced by Burton McCullom, Electrical Engineer of the Bureau. On the subject of inductive interference, the discussion covered in particular the question of methods by which the inductive interference problem can be attacked effectively. This problem is a very large and complex one, and the conference made no attempt to discuss the merits of different remedies for the difficulties which have arisen. It is understood that considerable progress has recently been made toward the cooperative study of this problem by the various utilities whose interests are more or less in conflict, and it is hoped that discussion of this matter by state engineers may develop some method by which state authorities and the Bureau can also cooperate effectively with the utilities.

Future conferences similar to this first one will be arranged to be held in various parts of the country in order to facilitate attendance by state engineers.

8. Use of Public Address Systems with Telephone Lines. W. H. Martin and A. B. Clark.

Use of Public Address System with Telephone Lines

BY W. H. MARTIN and A. B. CLARK

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The combination of the public address system and the telephone line makes it possible for a speaker to address simultaneously audiences located at a number of places. This paper discusses various applications of this combination, states the requirements for the lines, shows the circuit arrangements used and describes some of the important operating features.

A description is given of the system used on Armistice Day, 1921, when large audiences at Arlington, New York and San Francisco joined in the ceremonies attending the Burial of the Unknown Soldier at the National Cemetery at Arlington, Virginia.

The application of the public address system apparatus and methods to radio broadcasting is also briefly discussed.

THE public address system which is described in a paper by I. W. Green and J. P. Maxfield, was developed and first used for the purpose of extending the range of the voice of a speaker addressing an audience. With the aid of this system enormous crowds extending from the speaker's stand to points a thousand feet and more distant have in reality become an audience and have easily understood the speaker whose unaided voice covered only that portion of the crowd within a hundred feet or so from him.

When this system, consisting of a high quality telephone transmitter, distortionless multi-stage vacuum tube amplifiers, powerful loud speaking receivers and projectors, had so shown its capabilities, in reproducing speech sounds, a logical extension of its application was to use it with telephone lines. By connecting the transmitting and receiving elements of the public address system through a suitable telephone line a system is provided whereby a speaker can address an audience at a distant point. Also with a complete public address system at the point where the speaker is located, connected by lines to receiving elements of the public address system located at one or more distant points, the speaker is enabled to address a large local audience and to be heard simultaneously by audiences at one or more remote points. This last arrangement was first used on Armistice Day, 1921, when audiences at Arlington, New York and San Francisco joined together in the ceremonies attending the burial of the Unknown Soldier at the National Cemetery at Arlington, Virginia.

By means of the public address system, the meeting of this Institute at New York, at which this paper is presented is attended and participated in by Institute members at a meeting in Chicago. This is the first occasion on which complete public address systems installed at meetings in two cities have been connected together by telephone lines so that speakers at each meeting address the local and distant audiences simultaneously.

Presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 14-17, 1923.

With the transmitting element of the public address system working into the radio transmitter of a broadcasting station and with the receiving elements of the system connected to the output of the radio receiving sets, a system is provided whereby a number of people can be reached by each radio receiver.

The combination of these wire and radio communication channels with the elements of the public address system is, therefore, without limit in the number of persons who may be reached simultaneously by one speaker. Such combinations may prove extremely serviceable for occasions of nation-wide interest and importance.

The public address system apparatus has been used not only for transmitting speech sounds but also for music, both vocal and instrumental. The paper[1] describing the public address system has pointed out that the requirements for such a system are that for a wide frequency range it be practically distortionless, that is, transmit and reproduce with equal efficiency all frequencies in that range. This requirement must apply likewise to lines which are used with the loud speaker system. It has been found that a circuit which transmits without material distortion the frequency range from about 400 to 2000 cycles, can be used with the public address system to reproduce speech sounds which are fairly understandable under favorable conditions, although sounding unnatural. In general it is important to extend this range at both ends in order to improve the intelligibility of the sounds and increase the naturalness. For vocal and for some types of instrumental music the melody can be reproduced with the above frequency range, but these tones also are lacking in naturalness. Since some of the musical instruments are used to produce tones three and even four octaves below middle C, it is evident that the proper reproduction of music requires a further extension of the lower limit of the transmitted band than does speech. While the fundamentals of the higher musical tones lie in general in the range mentioned above, it is the harmonics in musical tones which dis-

1. Green and Maxfield, "Public Address System."

tinguish those produced by different instruments and which give what musicians term "brilliance." The true reproduction of many musical selections requires the distortionless transmission of a frequency band of from about 16 cycles to above 5000 cycles. Many musical selections, however, employ only a part of this range and accordingly can be satisfactorily reproduced by systems not transmitting the whole range. Also, even with slight distortion obtained with somewhat narrower ranges, reproductions may be given which are agreeable to many popular audiences.

Line Requirements

In general the same line requirements which make for satisfactory transmission of speech over commercial telephone circuits also make for satisfactory transmission when telephone circuits are associated with loud speakers. There is this difference however. The loud speakers tend to make the line distortion much more noticeable and serious. Speech transmitted over a particular telephone line is, in general, more difficult to understand when listening to loud speakers than when listening to telephone receivers.

In commercial telephone service the main requirement is intelligibility while, with the loud speaker, the naturalness of the reproduced speech sounds is very important. People are accustomed to hearing transmission through the air with very little distortion and naturally expect the same results with loud speakers.

The above constitute the reasons why, for transmitting voice currents over telephone lines with loud speakers, it is necessary to pay unusual attention to the electrical characteristics of the lines. Evidently when music is to be transmitted, particularly music of a fairly high grade, it is necessary to place even more severe electrical requirements on the lines.

An analysis of what constitutes the electrical requirements of a telephone line which make for good transmission, particularly when loud speakers are employed, will now be given.

In the first place, as explained above, it is essential that a sufficiently broad frequency range be transmitted. As explained in another paper[2] it is not sufficient that a telephone circuit transmit sustained alternating currents within a given frequency range. It must also transmit short pulses of alternating currents within the proper frequency range without introducing oscillations of its own or "transient effects." This requires that loaded circuits for loud speaker use have a high cut-off frequency and hence have the frequencies of the predominant natural oscillations high. It has been found that when the cut-off frequency of loaded circuits is about 5000 cycles, good results are secured with loud speakers.

The two types of telephone circuit which best meet the requirements of transmitting a broad band of frequencies, both when sustained and when applied in short pulses, are non-loaded open-wire lines and extra-light loaded cable circuits. These are suitable for transmission over very long distances. For transmission over short distances, say from one point in a city to another point in the same city, non-loaded cable circuits equipped with distortion networks or attenuation equalizers for equalizing the attenuation, give good results.

A good idea of the range of frequencies which can be transmitted over high grade telephone circuits can be secured from Fig. 1, which shows the transmission efficiency at different frequencies for the New York-San Francisco circuit. This circuit is a non-loaded No. 8 B. W. G. open wire line equipped with twelve telephone repeaters and is 3400 miles long. Its frequency characteristic meets very well the requirements for easy understanding of voice transmission although it causes some loss of naturalness.

The frequency range which can be transmitted with approximately constant efficiency is limited at the lower end by the fact that composite sets are employed in

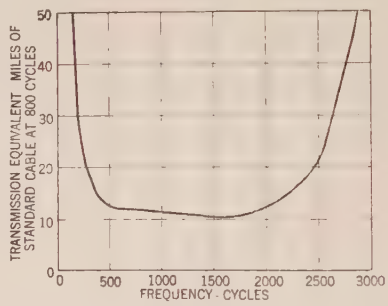

Fig. 1—Transmission Characteristic of Transcontinental Circuit—New York to San Francisco

order to make it possible to superpose direct current telegraph circuits. The elimination of these composite sets would make it possible to improve the transmission of low frequencies and thus improve the operation of the circuit in connection with loud speakers. The resulting improvement, however, would not be of importance for commercial telephone service and would render it more difficult to avoid noise on circuits exposed to induction from paralleling power or telegraph circuits.

At high frequencies the range is limited because these same wires are equipped with apparatus to permit super-position of multiplex carrier telegraph circuits above the voice range. This limitation also is not important for commercial telephone service although it is of importance for loud speaker use. To raise the upper limit of the voice transmission range would require giving up some of these facilities.

Fig. 2 will give an idea of how the distortion introduced by a length of non-loaded cable can be corrected by employing distortion networks or attenuation equalizers. This figure shows the transmission fre-

2. Clark, Telephone Transmission over Long Cable Circuits, Journal of A. I. E. E., January, 1923.

quency characteristic of about 10 miles of non-loaded No. 19 A. W. G. cable. Curve *A*, in the figure, shows the characteristic when uncorrected, while Curve *B* shows the characteristic for the circuit when equipped with an attenuation equalizer.

After choosing the proper types of telephone circuits for use in connection with loud speakers, there remains to be considered a number of other important matters.

The maintaining of the telephone power within proper limits at different points in the circuit is very important. The power must not be allowed to become too weak, otherwise the extraneous power induced from paralleling circuits would tend to obliterate the telephone transmission. On the other hand, the telephone power must not be amplified to such an extent that the telephone repeaters will be overloaded or severe cross-talk be induced into paralleling circuits.

To keep the telephone power throughout the circuit between the above limits, requires careful study and adjustment. For handling regular telephone connections, the circuits are laid out and equipped with

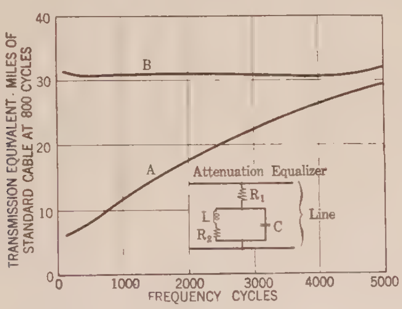

Fig. 2—Transmission Characteristic of No. 19 Gage Non-Loaded Cable Circuit
A—Without Attenuation Equalizer
B—With Attenuation Equalizer

repeaters at proper points so that each circuit will be able to handle the varying volumes applied at the terminals when different subscribers are connected without getting into serious difficulties. When loud speakers are employed it is necessary to maintain the volume at the terminals of the toll lines at least within these limits and it is preferable to do somewhat better than this.

With the public address system, the high quality transmitter which picks up the sound at the sending end is usually associated with an amplifier whose adjustment is varied, depending on the output of voice currents from the transmitter. In order to obtain the proper adjustment of this amplifier, it is necessary to have some means for quickly indicating the volume of transmission. For this purpose, there has been developed a device which is called a "volume indicator." This consists of an amplifier detector working into a direct-current meter. With this volume indicator connected across the output of the transmitter amplifier, the volume of transmission delivered to the line is indicated by the deflections on the meter. By adjusting the amplifier, therefore, to keep the deflections of this meter reasonably constant at some deflection determined by previous calibration, it is practicable to keep the telephone power within the required limits. Obviously, this same device may also be employed to keep the telephone power constant at any other point in the system.

While the necessity for keeping the power applied to the toll lines within proper limits cannot be over-emphasized, it should also be noted that this is not sufficient. It is also essential that all parts of the toll circuit, including the repeaters, be maintained at prescribed efficiency so that the power levels at all intermediate points in the circuit will also be kept within proper limits. Long telephone lines are designed with special emphasis on this matter of constant efficiency so that, in general, no special precautions are required when using these circuits in connection with loud speakers.

In another paper,[3] the "echo" effects which may occur on long telephone circuits are explained. When setting up two-way circuits for loud speaker use, it is necessary to pay particular attention to effects of this sort. Furthermore, there is another source tending to produce echoes in circuits arranged for two-way use with loud speakers. This is the tendency for the sound delivered from the loud speaker projectors to enter the sensitive transmitter and be returned to the distant end of the circuit as an echo. Owing to the relatively slow velocity of transmission of sound through air the lag in such an echo may be great enough to be serious, although the line is a short one with high transmission velocity. It is, therefore, evident that this coupling through the air between the loud speaker projector and the transmitter must be kept small. If a very sensitive transmitter arranged so that a speaker may stand several feet away from it is employed, this problem becomes even more difficult.

There is one thing more that remains to be considered: the necessity for special operation. When a large number of people are assembled at some point to hear an address delivered at a distant point, it is evident that delay in establishing the connections cannot be tolerated. It is, therefore, necessary to establish such connections ahead of time and it is usually also necessary to set up spare circuits for use in case of failure of the regular circuits. A special operating force is required for checking up the circuits, establishing the connections when required, and making the necessary adjustments. Rehearsals are necessary on important occasions to insure proper functioning of the circuits and proper coordination of the handling of the circuits with the programs at different points.

Typical Circuit Combinations of Public Address System and Lines

Following are a number of typical combinations of the public address system and telephone lines. The

3. Clark, *loc. cit.*

combinations by means of which one-way service may be rendered, are given first, following which certain combinations for giving two-way service are discussed.

By one-way service is meant service in which no provision is made for anyone in the distant audience to talk to the place where the speaker is located. Two-way service provides for speakers at either of two or more points addressing all of the other points. This is similar to the two-way service rendered by regular telephone circuits.

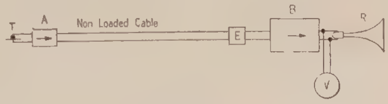

Fig. 3—One-Way Connection to Point in Same City

Fig. 3 shows the circuit arrangement which would be used when a speaker at one point in a city, for example, at his office, is to address an audience at another point in the same city. A high quality close talking transmitter T, together with a fixed gain single-stage amplifier A, are provided at the point where the speaker is located. This combination is designed to deliver to the line the same amount of power as a commercial type substation set. Connecting this point with the point at which the audience is gathered is a non-loaded cable circuit. To correct for the distortion in this cable circuit, an attenuation equalizer E is provided. The apparatus at the point where the audience is located is the equipment of the public address system without the transmitter and its associated amplifier. In Fig. 3, B is the amplifier for delivering sufficient power to the group of loud speaker projectors indicated by R. A volume indicator V associated with the amplifier B is used in maintaining constant the volume of sound delivered from the projectors.

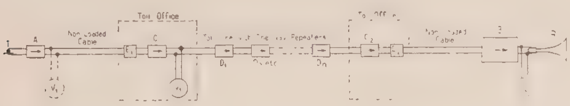

Fig. 4—One-way Connection to Point in Distant City

Fig. 4 shows the circuit combination required when a connection is to be established to a distant city where the loud speaking receivers are located. In the city where the speaker is located, connection is made to the toll office by means of a non-loaded cable circuit equipped with an equalizer similar to Fig. 3. A volume indicator V_1 is associated with the amplifier C_1 at the toll office to enable proper adjustment of amplifier C_1 to be made so that the power delivered to the toll line will be within the proper limits. As explained above if the volume at the toll office is allowed to become too great, the telephone repeaters on the toll line will be over-loaded and serious distortion will result, while if the volume is allowed to become too weak, extraneous noise and crosstalk will tend to obliterate the direct transmission. If a distant talking transmitter is used for the speaker, a multi-stage adjustable amplifier is associated with it. In this case the volume indicator is located at the output of this amplifier as shown by the dotted lines in Fig. 4. When the volume indicator is employed at this point it is necessary to take into account the loss introduced by the non-loaded cable and the equalizer E_1, together with the gain of the repeater C_1, in order to deliver volume within proper limits to the toll line. The toll line, shown equipped with repeaters D_1, D_2, etc., extends to the toll office in the distant city. At this point the amplifier C_2 is located, together with another equalizer E_2, for correcting the distortion in the local non-loaded cable circuit. The apparatus at the point where the audience is located is similar to that shown in Fig. 3.

Fig. 5 shows the circuit combination employed when a local address is to be given, while at the same time the same address is delivered to one or more distant points.

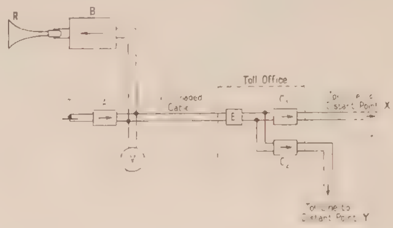

Fig. 5—One-way Connection for Addressing Local and Distant Audiences Simultaneously

In order to allow the local audience to hear the address by means of the loud speakers, the power amplifier B supplying energy to these is bridged across the output of the amplifier A associated with the transmitter T. A volume indicator V, connected across the circuit at the point where the bridge is made, makes it possible to maintain constant volume both for the local loud speakers and for the transmission applied to the toll lines by suitable adjustment of amplifier A. At the toll office means are indicated for connection to two distant points X and Y. Owing to the fact that amplifiers C_1 and C_2 are one-way devices, no interactions can occur between lines X and Y or between these lines and the local loud speaking system. The arrangements for reaching the distant points X and Y are similar to the one illustrated in Fig. 4.

Fig. 6—Two-way Four-Wire Connection for Addressing Local and Distant Audiences

All of the circuit arrangements which have so far been described are arranged simply so that a speaker may address one or more local or distant points. When it is desired that the speaker and the audience at the sending

end be able to hear, also, a speaker at the distant point, more complicated arrangements are required.

Fig. 6 shows a circuit arranged for such two-way service, the line being operated on the four-wire principle, *i. e.*, two separate transmission paths are provided, one for transmission in each direction. The circuits connecting transmitter T_1 with the projector group R_2

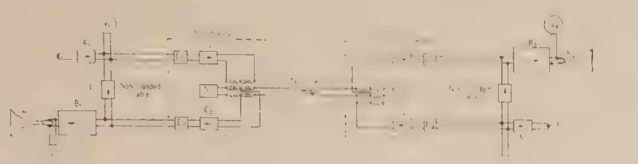

Fig. 7—Two-way Two-wire Connection for Addressing Local and Distant Audiences

and transmitter T_2 with the projector group R_1 are similar to the circuit in Fig. 4. By-pass connections F_1 and F_2 are added at the two ends which allow part of the output of each transmitter to pass into the local loud speakers. These by-pass connections are so arranged that transmission can pass only in the proper direction. Two volume indicators are provided at each end. Referring to the left-hand terminal, volume indicator V_1 is provided to insure that power is supplied to the toll line within the proper limits of volume, as explained above. V_3 is provided to facilitate adjustment of the by-pass circuit F_1 and of amplifier B_1 so as to deliver proper volume from R_1 both for the local talking and for the reception of the addresses from the distant end of the circuit. The volume indicators V_2 and V_4 at the right-hand end of the circuit have functions similar to those of V_1 and V_3 respectively.

Fig. 7 is similar to Fig. 6 with the exception that the toll line is of the two-wire type. At each end of the toll line, which may, or may not, contain two-way repeaters, transformers and networks N_1 and N_2 are placed for converting the two-wire circuit into a four-wire circuit. The equalized cable circuits at the two ends thus form two sides of short four-wire circuits. The conditions of balance between the networks and the toll lines prevent more than a very small amount of the direct transmission from each local transmitter from entering the local loud speaking receiver circuit at the points where the local circuits connect to the toll line. Practically all of the transmission from transmitter T_1 to projector group R_1 and from transmitter T_2 to projector group R_2 is delivered through the adjustable by-pass circuits F_1 and F_2, respectively.

For connections requiring to and fro conversations between three or more points, all of which may be equipped with loud speakers, intermediate points may be connected to a two-wire telephone circuit by employing the arrangement shown in Fig. 8. A three-winding transformer is inserted in the toll line which is so constructed that the impedance which it introduces into

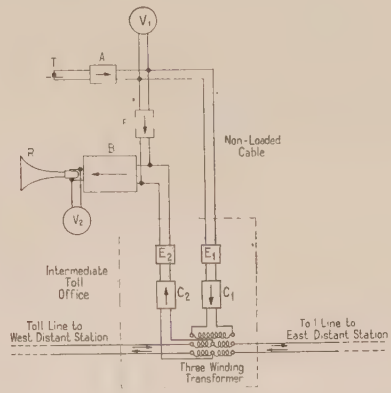

Fig. 8—Arrangement for Connecting Third Point to Circuit of Fig. 7

the circuit is small enough to avoid a serious irregularity. Talking currents are put out on to the toll line through this transformer. The received transmission is obtained from a high impedance bridge across the midpoints of two of the windings of the three-winding transformer. Amplifiers C_1 and C_2 introduce sufficient gain to overcome the losses due to the inefficient coupling with the telephone line. The rest of the circuit at the intermediate point is the same as Figs. 6 and 7, the local speaker being heard by his own audience by means of transmission delivered through by-pass F. A modification of the arrangement of Fig. 8 can, of course, be used with a four-wire toll circuit.

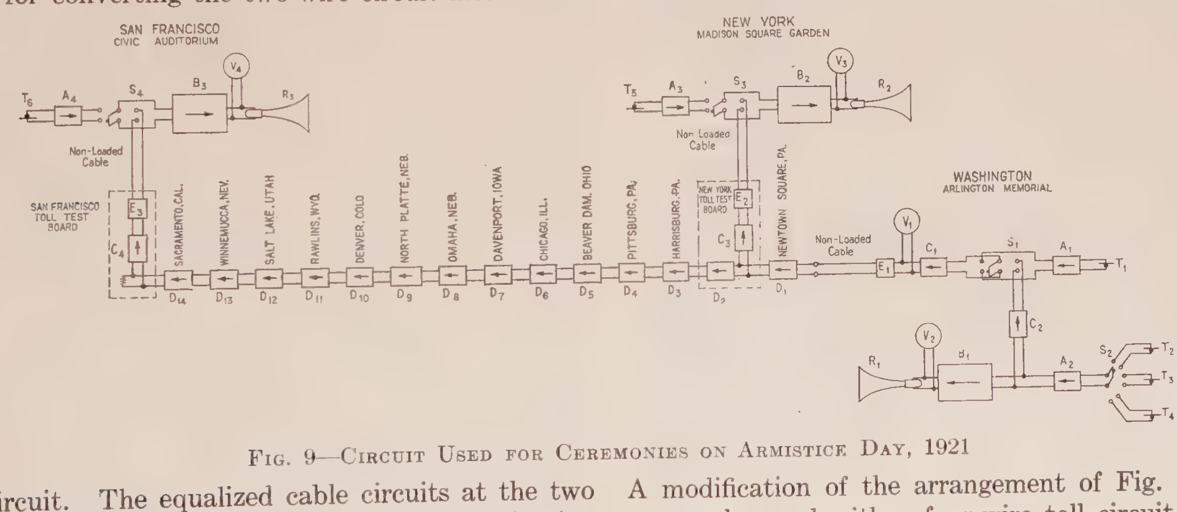

Fig. 9—Circuit Used for Ceremonies on Armistice Day, 1921

Arrangements for Armistice Day, 1921

Fig. 9 shows the circuit which was employed on Armistice Day, 1921, when audiences of 100,000 people at Arlington, 35,000 people at New York and 20,000

people at San Francisco, joined in the services at the burial of the Unknown Soldier. This was the first time that audiences at more than one distant point were simultaneously addressed from one point by means of the public address system.

At Arlington three different transmitters T_2, T_3 and T_4 were used for the different parts of the ceremonies. T_2 was used for the musical selections, T_3 for the speeches made in the amphitheatre, and T_4 for the speeches at the grave of the Unknown Soldier. Another transmitter T_1 was provided for the use of an announcer who kept the audiences at New York and San Francisco advised of the proceedings. The speech currents leaving these transmitters were brought up to moderate volume by means of amplifiers A_2 and A_1, the former taking care in turn of the three different transmitters employed during the ceremonies.

The voice currents from the transmitters which were employed for the ceremonies, after passing through amplifier A_2, separated into two branches, one branch going to the local amplifier B_1, which supplied the local loud speakers R_1, the other going to the telephone circuit through amplifier C_2, switch S_1 and amplifier C_1. The switch S_1 was provided for connecting either the announcing transmitter T_1 or one of the transmitters for picking up the ceremonies to the end of the toll line. V_1 and V_2 are volume indicators, V_1 being employed to indicate that the proper power was being put into the toll line, while V_2 furnished an indication of the volume which was being delivered by the projector group R_1. During the ceremonies the amplifier C_2 was continuously adjusted so as to deliver proper volume to the long distance telephone circuit, the volume indicator V_1 making it possible to keep the volume applied to the toll line within close limits. At the same time independent adjustments were made of the amplifier B_1 to take care of the varying conditions introduced by the different talking conditions as well as the varying conditions introduced by shifting of the crowds listening to the ceremonies.

After leaving the amplifier C_1 at Arlington, the voice currents first passed through a non-loaded section of cable whose distortion was corrected by equalizer E_1. A non-loaded 8-gage open-wire circuit carried the voice currents to New York City. At this point, the circuit again branched, one branch delivering a part of the voice currents to the apparatus at Madison Square Garden, the other branch going to San Francisco over one of the non-loaded No. 8 gage transcontinental circuits. The arrangements employed at Madison Square Garden and at the Civic Auditorium in San Francisco were similar, switches being provided at each point to connect to the projector groups the circuit from Arlington or from the local transmitter.

The difficulties involved in transmitting voice currents for the first time to loud speaker installations at distant points, as well as the great importance of the occasion, made it necessary to take elaborate precautions in order to insure the success of the undertaking. The long distance telephone circuits were carefully inspected ahead of time and all of the amplifiers and other apparatus employed were subjected to numerous careful tests. For checking the complete circuit, alternating currents of different frequency were applied at Arlington and measured simultaneously at New York and San Francisco. The curve on Fig. 1 was obtained from the results of one of the measurements made on this occasion.

To guard against possibility of failure of the circuits, emergency circuits were provided, these emergency circuits taking different routes wherever possible. Fig. 10 shows the network of long distance circuits which was set up for this occasion. The solid lines in this figure indicate telephone circuits while the broken lines indicate telegraph circuits. The latter were for the purpose of transmitting orders between different units of the operating organization at different points.

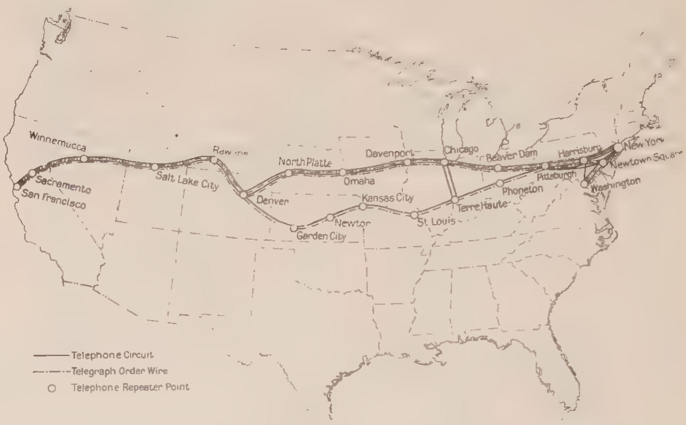

Fig. 10—Telephone and Telegraph Lines Used on Armistice Day, 1921

At Arlington the nature of the ceremonies and the place in which they were held presented many difficulties from the acoustic standpoint. The main addresses were made in an open amphitheatre surrounded by a double colonnade of marble. The platform on which the speakers were located was partially covered by a marble arch. The floor of the amphitheatre is of cement on which are arranged marble benches. Temporary seats also were placed on top of the colonnade. During the ceremonies large crowds surrounded the amphitheatre on all sides. The arrangement of the amphitheatre and the surroundings is shown by Fig. 11.

In order that the crowds outside of the amphitheatre might hear the speakers, loud speaking receivers and their associated projectors were placed on top of the colonnade. They were arranged in four groups as shown on Fig. 11, the projectors referred to, being numbered from 1 to 21 inclusive. Those in the east group were on top of the structure forming the main entrance to the amphitheatre. The projectors were

carefully directed to cover uniformly the area around the amphitheatre and were supplied with sufficient power so that the speaker could be heard for at least a thousand feet from the outside of the amphitheatre. It was found, however, that while these projectors are highly directive, some of the sound from them could be heard inside the amphitheatre. This sound leakage at the western side was particularly serious because of the fact that it reached the rear seats inside of the amphitheatre sufficiently far enough ahead of the corresponding sounds directly from the speaker to be noticeable. To overcome this, the small projectors 29, 31, 32 and 34, placed on top of the arch over the platform, were directed at the rear seats and given sufficient volume output to overcome the sound reaching these seats from the loud speakers on the colonnade.

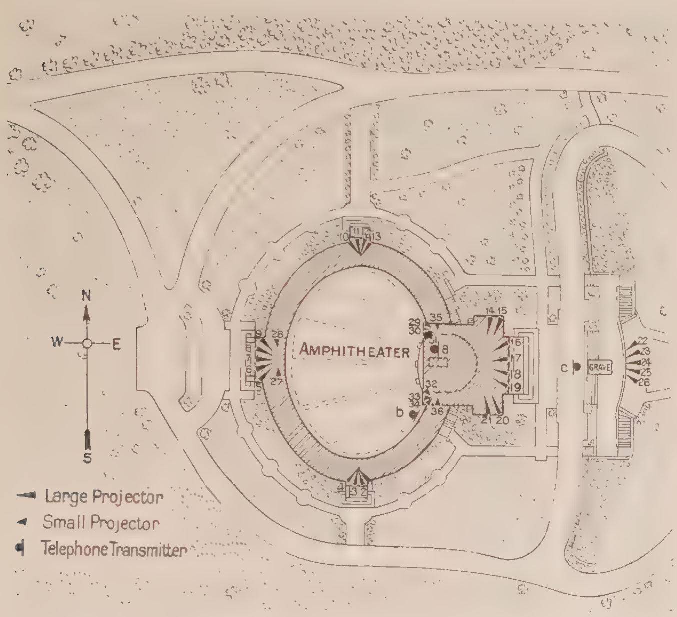

Fig. 11—Arrangement of Projectors at Arlington Amphitheatre

The adjustment of the power to these small projectors required great care because if given too great volume, bad reflections would be set up in the amphitheatre. On the other hand if this volume were not great enough, the outside projectors would cause serious interference. The small projectors 27 and 28 were used to overcome the sound leakage effects on the top of the west side of the colonnade. The projectors 35 and 36 covered the top of the colonnade on the east side.

Fig. 11 shows also the location of the three transmitters used during the ceremonies, *a*, on the platform for the speakers, *b*, in front of one of the boxes in which were placed the singers and behind which was located the band, and *c*, at the grave. When the transmitter at the grave was tested it was found that serious interference was obtained between the speaker's voice and the sound from the projectors 16 to 19 inclusive. For the ceremonies at the grave, therefore, these loud speakers were disconnected and those numbered 22 to 26 used instead. Also in order to properly cover the inside of the amphitheatre during the ceremonies at the grave, the small projectors 30 and 33 were used. These were located on the arch over the platform and were directed at the front seats in the amphitheatre.

The projectors were divided up into a number of small groups and so connected that the volume of sound delivered by each group could be varied without affecting the other groups. This was necessary in arriving at the power to be delivered by each projector to give uniform distribution and to avoid interference between different groups.

By means of these arrangements all parts of the ceremonies were carried to all parts of the audience at the National Cemetery and were also delivered by means of the lines to the audiences in the distant cities.

At New York, a group of fifteen loud speakers was used in Madison Square Garden to satisfactorily reach all parts of the audience and a group of twenty-one loud speakers was suspended outside the building for the outside audience. At San Francisco, ten loud speakers were used in the Civic Auditorium and seven outside.

Use of Public Address System Apparatus with Radio

When radio broadcasting came into general use, the apparatus and methods which had been developed for the public address system were applied to this new field as it also demands high quality reproduction for speech and music. The transmitters and amplifiers associated with them in the public address system are used in radio broadcasting studios for delivering speech frequency electrical power to the radio transmitter. Loud speaking receivers and amplifiers for delivering sufficient power to operate them are used with many of the radio receiving sets.

The methods which have been employed to connect public address system transmitters with toll lines are being used for the broadcasting by radio of speeches and music given at points remote from the radio station. In such cases the transmitter and its associated amplifier are operated and controlled in the same way as described above for toll lines. In some cases the radio station is in the same city as the place where the speech or music is given and in other cases the two have been in different cities. In the first case the output of the transmitter amplifier is carried to the radio station over non-loaded cable circuits which are equalized by means of distortion correction networks to have uniform efficiency over a wide frequency range, in some cases up to 5000 cycles. Where the two points are in different cities, the non-loaded cable circuit goes to the toll office and there is connected to the toll lines which are operated in the same manner as described above for loud speaker use.

For some of the higher grade music, such as that given by symphony orchestras, the less efficient, but slightly higher quality condenser type transmitter has been used instead of the double button carbon type. This requires the use of ana dditional two stage amplifier in front of the regular three stage transmitter amplifier.

The output of the transmitter amplifiers is controlled with the aid of a volume indicator bridged across the output terminals of the amplifier. For best results, particularly in reproducing music, it is necessary to adjust the gain of these amplifiers to compensate partially for the large range in the volume of the music. If the amplifiers are set high enough in gain to send through the low passages of the music with sufficient volume so that it will override the static and the interference from other sending stations, the loud parts of the music will seriously overload the radio transmitter system, unless it is of very large capacity, and will in general overload the receiving sets. Furthermore, putting out these loud parts at the same relative level with respect to the low passages as they are given by the orchestra, makes the interference between radio stations more serious. In some orchestral concerts the power amplification of the transmitter amplifier has been adjusted over a range of more than a hundred to one, these changes being made, however, so that they were not noticed by those listening to the concert by radio.

Proper volume control is very important in picking up such music for radio broadcasting. The lack of such control is responsible for many of the poor results that are being obtained. In this connection, the location of the transmitter with respect to the various instruments in the orchestra or smaller combination of instruments, so as to maintain in the reproduced music the proper balance between the several parts is, of course, of great importance.

An interesting illustration of the combination of the public address system, telephone lines and radio broadcasting was used in connection with reporting a football game played in Chicago in the fall of 1922. By means of high quality transmitters and amplifiers located at the football field, announcements of the plays and the applause of the spectators were delivered to a cable circuit extending to the toll office in Chicago. This circuit was connected there to a toll line to New York where it delivered the telephonic currents to a radio broadcasting transmitter. In Park Row, in New York City, was located a truck on which was mounted a radio receiving set arranged to operate a public address system. By this means the reports of the plays of the football game in Chicago were delivered to a large crowd in the streets of New York.

The recently adopted standard sizes and tests for dry cells and flash light batteries are given in a revised edition of Circular 79 issued by the Bureau of Standards. These tests and sizes were adopted by a conference of the leading manufacturers, government representatives, and large individual users.

MASSACHUSETTS STARTS ENFORCEMENT OF TAIL-LIGHT LAWS

More than half the States of this country have for a number of years had Motor Vehicle Tail-Light laws in which are specified the minimum distance at which the warning light itself should be visible, and also the minimum distance at which the license tag should be legible at night. Although the requirements of individual States vary considerably, the intent of these laws is good; that is, to protect the motoring public, unfortunately, however, until very recently no serious attempt has been made to strictly enforce tail-light laws. As a result, tail-light design has been given little thought.

It is not surprising then that the State of Massachusetts upon taking up the matter of enforcement found that not a single tail-light then in use met the requirement that the license plate be legible at night for a distance of 60 feet. It has been necessary, therefore, for all automobile manufacturers to redesign their tail-light equipment and for the motoring public of Massachusetts to provide itself with tail-lamps of approved design.

To meet the legal requirements in this State tail-lamps differing from approved designs must be submitted to the state laboratories for test and approval. Specifications having a direct bearing on illumination are:

1. Two- or four-candle power lamps only may be used;

2. The lamp must be mounted above the center of the number plate;

3. The filament of the lamp must be within a certain definite zone;

4. The window in the tail-lamp housing must be covered with glass and of such size that light from the entire filament will strike every part of a $14\frac{1}{2}$ by $6\frac{1}{2}$ inch number plate and clear the bottom of the plate by at least $1\frac{1}{2}$ inches.

The tail-light problem was discussed in a recent joint meeting of Committees of the Illuminating Engineering Society and Society of Automotive Engineers, with the idea of developing and standardizing regulations very similar to those in Massachusetts, but so worded as not to impede progress along this line in the way of new developments. It is expected that Massachusetts will adopt these specifications when they are published.

In view of the fact that other States have laws very similar to those in Massachusetts, it is possible that they also will become active on this matter. In any event the action of Massachusetts in causing its 450,000 car owners to provide effective tail-light equipment and automobile manufacturers to adopt approved tail-lamp designs, will in time result in better rear number plate illumination throughout all sections of the country.

Colloid Chemistry*

BY WILDER D. BANCROFT

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THE Chairman of your Program Committee wrote to me that he wished my talk to be a popular presentation which would interest the members who came to the meeting and also a profound discussion which could be read with profit by the eighteen thousand members who decided not to come. Either alternative is a large order and the two are mutually inconsistent, so I am not likely to satisfy anybody. Your Chairman evidently forgot that, if I were to tell you all the things which I consider interesting about the theory of colloid chemistry, I should keep going for several weeks. I give my unfortunate class at least twenty-five lectures at full speed on this very point. I am going to compromise tonight by telling you of a few things which might reasonably be of interest to electrical engineers, without making any attempt to cover the whole ground.

Speaking broadly, we can define colloid chemistry as the chemistry of bubbles, drops, grains, filaments, and films. These are things of which at least one dimension is small. In other words colloid chemistry is the chemistry of materials in which the surface is large relatively to the mass. For this reason one rather flippant person suggested calling the subject superficial chemistry; but some of us objected to the connotations.

Not so very long ago it was the fashion for the lecturer to present colloid chemistry as a succession of miracles. It was said to constitute a separate world of matter in which none of the facts of ordinary chemistry are so. Barium sulphate and metallic gold are soluble in water; metallic silver is blue, red, or yellow; globulin has a gram molecular weight of 700,000; a suspension of gamboge in water behaves like an ideal gas with a molecular weight of 200,000 tons; colloidal platinum is an inorganic ferment and is poisoned by potassium cyanide or by corrosive sublimate; all systems are in a state of flux undergoing irreversible changes.

Fortunately those days are over and we now try to make the phenomena of colloid chemistry seem the most obvious things in the world. If we start with adsorption and the Brownian movements, everything else follows fairly satisfactory; but these two concepts have not been familiar ones to the chemist and are perhaps quite unknown to the electrical engineer.

One property of every surface is that the surface tends to condense upon itself everything else with which it comes in contact in amounts which vary with the nature and structure of the surface, the nature of the substance in contact with the surface, the pressure, and the temperature. This formation of a surface film with a relatively high concentration is called adsorption. To most of us that seems a harmless name for an observed fact; but there are people who do not like it. A distinguished biological physicist from Cincinnati claims that the crime of the century is not the demonetization of silver, but the way in which colloid chemists sail under the black flag of adsorption. This metaphor seems to me a bit mixed but that is of no importance. It is possible also that I may have misrepresented my friend. It may be that the demonetization of silver was the political crime of the last century and that adsorption is the chemical crime of this century.

We know that adsorption takes place and that it is specific; but we do not know why hydrogen or carbon monoxide concentrate at, or are adsorbed by, a charcoal surface, for instance. One explanation is that the hydrogen or the carbon monoxide is attached to the surface of the charcoal either by regular chemical bonds or by contravalences, thus forming something analogous to a chemical compound. We cannot go any further than this because the carbon particles in the charcoal hold to each other more firmly than they do to the hydrogen, which would not be the case if methane, acetylene, ethylene, or ethane had been formed. For most purposes, however, it is quite sufficient to know that hydrogen concentrates at, or is adsorbed by, a charcoal surface without bothering our heads as to the mechanism of the adsorption.

While the phenomena due to adsorption constitute practically the whole thing in colloid chemistry, we cannot dispense with the Brownian movements, when we are dealing with fine particles suspended in a liquid. If we drop a very fine particle of sand in water, the sand will tend to sink because it is denser than the water. According to the kinetic theory, the water molecules are in violent motion and consequently will bombard the sand particle continuously. If the particle is large relatively to the molecule, the bombardment will have relatively little effect upon it; but if the particle is very small, it will be driven first one way and then another by the buffeting of the water molecules. This actually happens and, under the microscope, the finely-divided particles of any solid may be seen moving continuously in a zig-zag fashion. This phenomenon was first observed in 1828 by an English botanist named Brown and was named after him.

As would be expected from the theory, the Brownian movements are less marked the larger the particles. In fact, there is no perceptible motion when the particles exceed 4 μ in diameter, while particles with diameters of about 10 $\mu\mu$ give apparent trajectories up to 20 μ. The speed of platinum particles having a diameter of 10-50 $\mu\mu$ has been estimated by Svedberg at 200-400 $\mu\mu$ per second; but Perrin does not believe that these estimates are accurate. With increasing vis-

*Lecture presented at the A. I. E. E. Midwinter Convention, February 16, 1922.

cosity of the liquid the Brownian movements decrease, which is what one would expect on any hypothesis.

It is easy to see that the bombardment by the water molecules will give rise to irregular movements; but I should have supposed that the general effect would have been equivalent to a fairly uniform bombardment from all sides. This is not the case, however, and, for some mathematical reason which I have never understood, the statistical effect is a greater bombardment from the bottom than from the top when the suspended particle is denser than the liquid and the reverse when the particle is less dense. This is so judiciously arranged that the force of gravity is balanced and consequently this absolutely hit-or-miss bombardment results in a practically uniform distribution of the particles throughout the mass of the liquid.

This practically uniform distribution occurs only when the particles are very fine and consequently it follows that we shall get a colloidal solution whenever we have sufficiently fine particles and keep them fine. If several of the fine particles agglomerate or coalesce to form a large particle, the Brownian movements will be unable to keep this larger particle suspended and it will sink to the bottom or rise to the top as the case may be.

There are two different ways in which we can keep fine particles from coalescing or agglomerating. One is to coat them with a suitable material film. You are perfectly familiar with this on a somewhat larger scale and under other conditions. You know that you can buy a pasteboard box containing several separate doses of a liquid medicine, castor oil for instance. The separate masses of liquid do not run together because each one is enclosed in a gelatine capsule. We can do the same thing with suspended particles. We can coat them with a film of gelatin or some other substance which will keep them from coalescing. In some extreme cases a film of adsorbed water or other liquid will prevent agglomeration. Water seems to do this for tannin. When pyroxylin is carried into apparent solution by acetone, the separate particles are kept from coalescing by a film of adsorbed acetone.

We can also keep suspended particles from coalescing by charging them electrically all with the same sign, in which case they tend to repel each other. If we have suspended particles which adsorb hydrogen ions very strongly and chlorine ions very slightly, we can stabilize that colloidal solution by adding hydrochloric acid, in which case the particles will all be charged positively by the adsorbed hydrogen ions. If the particles adsorb hydroxyl ions very strongly and sodium ions only slightly, we can stabilize such a colloidal solution by adding alkali. If we add caustic soda to hydrous chromic oxide, the latter goes into apparent solution and we get an apparently clear, green solution of what used to be called sodium chromite. Nowadays we know that it is a colloidal solution of chromic oxide, the oxide particles being charged negatively by adsorbed hydroxyl ions. Of course a colloidal solution which is stabilized by the adsorption of an ion, will be precipitated if we add an electrolyte which has a readily adsorbable ion of the opposite sign from that which stabilizes the solution. You are probably quite familiar with Acheson aquadag which stays up admirably in water but flocculates when salt is added.

Precipitation occurs on a large scale when muddy rivers flow into the sea. When rain falls in a clay country, the run-off is muddy. The Mississippi river is very muddy at St. Louis; but there is a good deal of relatively coarse clay in it, most of which settles out gradually. At New Orleans the river normally has much less clay than at St. Louis; but the clay particles are very fine and show very little tendency to settle. They are charged negatively by adsorbed hydroxyl ions and that checks coalescence. When the river flows into the Gulf of Mexico, the concentration of sodium ions is so great in the salt water that it more than makes up for the relatively slight degree of adsorption of the sodium ions and the adsorption of these latter neutralizes the negative charge on the clay which therefore precipitates, forming a delta. Of course, there is some settling, due to the current becoming zero; but the chief factor in the formation of deltas is the precipitation of the suspended clay by the salts in the sea water.

At one time we used to distinguish between colloidal solutions stabilized primarily by adsorbed ions and those which were not, calling the first suspension colloids and the second emulsion colloids, the particles in the first being solid and precipitated readily by electrolytes, while the particles in the second were liquid and were relatively insensitive to electrolytes. A classification of this sort is valuable in the early days; but it emphasizes differences which are not real and consequently such terms as suspension and emulsion colloids are now practically obsolete. We can make oil suspensions which are quite as sensitive to electrolytes as colloidal gold. Colloidal sulphur, though charged negatively, withstands high concentration of hydrochloric acid. Gelatin solutions are not affected much by most salts; but recent work shows that the hydrogen ion concentration is important. In other words, we get all gradations and there is nothing to be gained by making arbitrary distinctions.

Gelatin is interesting because certain special things coagulate it and make it insoluble. Tannin is one and chromic salts are another, If we add tannin or a chromic salt to gelatin, we make it insoluble. This is utilized technically in making leather. Vegetable tanning consists in adding tannin to the hide substance, which is very similar to gelatin and becomes insoluble. In chrome tanning we make the hide substance insoluble by the addition of chromic salts. This phenomenon is also made use of in certain photographic processes. Bichromate has no effect on gelatin; but

if a bichromated gelatin is exposed to light, there is a reduction to a chromic salt and the gelatin therefore becomes insoluble where the light has struck it.

Having explained what we mean by colloidal solutions, I will take up a few cases of adsorption which may be of interest to you. A striking illustration is the gas mask in which the chief adsorbing agent is charcoal, which is very specific in its action, adsorbing certain substances much more strongly than others. If charcoal had adsorbed air in preference to poison gases it would have been useless as a protection against these latter. It was necessary that the charcoal should adsorb the toxic substances preferentially, that it should adsorb them very completely, and that it should adsorb them very rapidly. The requirements were very severe. The air may take only one-tenth of a second to pass through the canister and yet it may be necessary in that space of time to reduce the concentration of the toxic gas from, say, 1000 parts per million to 1 part per million or less. The charcoal developed by the Chemical Warfare Service met that requirement with a safe margin. In fact, in laboratory experiments, it was shown that the charcoal will reduce the very high concentration of 7000 parts per million of chloropicrin, $CCl_3 NO_2$, in a rapidly moving current of air to less than 0.5 parts per million in something under 0.3 seconds. This was, of course, a special charcoal. On the first of July, 1917, the best charcoal that we had would not stop chloropicrin for one minute under the conditions of the standard test. The charcoal, made on a small scale later, stood up at least 1200 minutes against chloropicrin under the same condition. This gives an idea of what was done in the way of improvement, though the large-scale manufacture of charcoal did not give so effective a product.

The early use of charcoal as an adsorbent was quite a different one and runs back to the end of the eighteenth century. Solutions of raw sugars are dark colored but can be decolorized by treatment with charcoal. The charcoal takes out nearly all the coloring matter and only a little of the sugar and we therefore have a very effective purification. Here too the chemist has developed much better charcoals than were used originally. It is worth noting, however, that the charcoals which are best in the gas mask are not the best for decolorizing sugar. The two sets of service conditions are quite different. Although contact catalysis involves adsorption, it does not follow that the charcoal, which is the best catalytic agent for making phosgene, $COCl_2$, from carbon monoxide and chlorine, is either the best charcoal for the gas mask or the best charcoal for decolorizing sugar.

When decolorizing sugar, we are not interested in the fact that, theoretically, the coloring matter, which is removed from the sugar solution, changes the color of the charcoal. We have other cases of adsorption in which the important thing is the fixing of the coloring matter on the adsorbing agent. If we dip a piece of cloth in a suitable colored solution, and perhaps heat the solution to boiling, the cloth will take some or all of the coloring matter out of the solution and will be dyed. We distinguish a number of different types of dyes such as basic, acid, substantive, mordant, vat, and sulphur dyes. Some of these are in true solution and some are in colloidal solution; but in all these cases we are dealing with an adsorption of the dye or of a reduction product of the dye either by the fiber itself or by the mordanted fiber, and the mordanting of a fiber is also a case of adsorption.

When discussing charcoal, a reference was made to the catalytic manufacture of phosgene. It has long been known that porous materials accelerate certain reactions and that this effect is specific. This acceleration of reaction velocity by an undissolved substance which undergoes no marked change itself, is known as contact catalysis and is of the greatest value in technical processes. The so-called contact sulphuric acid is made by passing a mixture of carefully purified sulphur dioxide and air over finely divided platinum at about 450 deg. In the synthesis of ammonia from hydrogen and the nitrogen of the air, porous iron is the chief catalyst, though other substances, known as promoters, are added to increase the action of the iron. The oxidation of ammonia to nitric acid is done in the presence of platinum as catalytic agent, while nickel is used chiefly in the hydrogenation of oils. In making ethylene from alcohol as a preliminary stage in the manufacture of mustard gas, either alumina or kaolin is used as the catalytic agent. As yet, we do not know how the catalytic agent activates the reacting substance and we cannot predict at all what substances will make the best catalyzers in any given case. If we ever get a satisfactory theory of the subject, I think that catalytic methods of making all sorts of chemical compounds will drive out pretty nearly all the regular processes. The plants act in that way now, their catalytic agents being called enzymes.

If we have electrified particles, as we do in some of our colloidal solutions, they will move under the influence of a direct current. As electrical engineers you are familiar with the particular case of electrified solid or liquid particles in air, which is known as the Cottrell process for precipitating smokes. A high-voltage, direct current passes from a point to a plate, ionizing the air and charging the suspended particles, which are carried to the plate and can there be scraped off. I have seen the statement that, in the Washoe reduction works of the Anaconda Copper Company, the Cottrell process has been introduced on so large a scale that the point electrodes consist of one hundred and eleven miles of chains. The Cottrell process removes suspended solids or liquids; but, of course, will not remove a gas, such as sulphur dioxide for instance.

In the case of a colloidal solution, the charged particles will move with the current if they are charged positively, through having adsorbed a cation, and they

will move against the current if they are charged negatively, owing to adsorption of an anion or to having emitted a cation. This transference under electrical stress consists in a motion of the particles relatively to the water. If we should in any way hold the particles stationary and leave the water free to move, we should expect an electrical stress to cause the water to flow past the particles, the water going to the anode if the particles are charged positively and to the cathode if the particles are charged negatively. This can be realized if we consolidate the particles into a porous diaphragm. Suppose we have a porous cup in a beaker with one electrode, the cathode, inside the cup and the other electrode, the anode, outside the cup. If the diaphragm is charged negatively, the liquid will flow through into the porous cup, eventually causing it to overflow. When the liquid passes through a diaphragm, the phenomenon is called electrical endosmose; when the suspended particles are carried through the liquid, the phenomenon is called cataphoresis. The word hylophoresis, or transport of matter, has been suggested as the general term covering both cases; but it has not yet been adopted.

Cataphoresis is the thing that has made electrolytic lead refining commercially feasible. Glue, or some similar material, is added to the bath and is carried to the cathode, where it modifies the structure of the lead so that it comes down as a fine-grained deposit and not as feathery crystals. The use of so-called addition agents is quite common in electro-plating and many of these are colloidal. The commercial applications of electrical endosmose have not been very successful as yet. By placing peat between two electrodes and passing a high-voltage current, the peat acts as a diaphragm and the water is squeezed out electrically. The water content of the peat can be reduced from ninety to sixty-five per cent with a reasonable expenditure of power; but the cost of getting the water content down to twenty per cent has proved excessive. The method is said to have been used successfully in drying alizarine paste and things of that sort, where the value of the product justified a greater expenditure for drying.

In addition to the adsorption of a gas or a liquid by a solid, we may also have the adsorption of a solid by solid. Several cases of this sort are of great interest to the electrical engineer. Theoretically, aluminum should be an utterly useless metal because it stands in the electrochemical series near the alkali metals and calcium, quite close to magnesium. We should expect it to corrode rapidly under almost any conditions; but that is not what happens. The reason that you can use aluminum for transmission lines, when the price of copper soars, is simply and solely because aluminum as a metal is a successful failure. Its natural duty in life is to corrode; but the oxide or hydroxide film which is formed is adsorbed so strongly by the metal that it protects the surface and thus stops further corrosion. The only reason why an aluminum wire or sauce-pan does not corrode is because the air and liquids do not come in contact with the metal. If we amalgamate aluminum, the oxide coating does not adhere and the metal corrodes rapidly, giving us the so-called fibrous alumina.

Nickel also becomes covered ordinarily with a strongly adsorbed film of oxide or hydroxide and consequently does not rust. In the case of iron the oxide film is usually not coherent and consequently the metal goes on rusting. It is possible, however, under special conditions, to give iron a coating of the magnetic oxide which protects the metal surprisingly well.

We speak of noble metals as ones that do not corrode in the air; but it is an open question in my mind how many metals can qualify under this definition. We know that platinum black is always oxidized in contact with air, which makes it probable that sheet platinum has an oxide film on it. Under ordinary conditions most of our metals do rust or corrode; but a good many of them, fortunately for us, stop corroding because of the formation of a protecting film. Zinc corrodes superficially and we all know that a copper roof turns green and then undergoes very little further change. As I see it, the corrosion problem is to treat a metal so that it will corrode to a limited extent and then stop. In other words we must study the conditions which cause the formation of a protecting film. Calorized iron is one solution of the problem, phosphatized iron is another solution, and there are doubtless many more.

A protecting film is not always a desirable thing. The difficulty in condensing zinc from zinc vapor is due to the fact that any zinc oxide which is formed is adsorbed strongly by the globules of liquid zinc as they form and we get blue powder instead of cast zinc. It is very difficult to melt aluminum scrap because of the oxide film around each piece. You are familiar with the fact that when dirty mercury is shaken, it forms globules which do not coalesce because of films of oxide or grease around each drop.

This brings us naturally to the question of emulsions, which are drops of one liquid suspended in another liquid. Since the two liquids in the ordinary emulsions are usually water and some form of oil, it has become customary to use the word oil for the non-aqueous liquid even though, as in the case of benzene, it is not strictly an oil. While we can make emulsions which are stabilized by an adsorbed ion, most actual emulsions are stabilized by the use of an emulsifying agent which forms a film around the drops of the suspended liquid. To emulsify oil in water, we are apt to use a sodium soap in the laboratory, while the pharmacist uses gum acacia a great deal. We can emulsify water in oil by using calcium soaps as in the case of some lubricating greases or we can use rosin in the case of paints in linseed oil. Whether we get water emulsified in oil or oil emulsified in water depends on the nature

of the emulsifying agent and not on the relative masses of oil and water. Speaking broadly, an emulsifying agent, which goes more readily into water than into oil, will emulsify oil in water. The converse is also true. Emulsions are very important physiologically because Clowes has shown that protoplasm behaves in many respects like oil and water emulsified by a mixture of calcium and sodium soaps, the lipoid material being considered as oil.

If we replace the oil in an emulsion by air or a gas, we have a foam. You have probably seen advertisements of Foamite as a means of putting out fire. This consists of solutions of aluminum sulphate and sodium bicarbonate to which has been added some organic material such as licorice. When the two solutions are mixed, the chemical reactions may be written,

$$Al_2(SO_4)_3 + 3NaHCO_3 = Al_2O_3 + 3Na_2SO_4 + 6CO_2 + 3H_2O.$$

The alumina and licorice form a film round the bubbles of carbon dioxide giving a very stable foam.

A more important application of foam is the ore flotation process. If we shake up water to which a little oil has been added, we get a bubble of air surrounded by an oil film. This bubble is fragile and breaks on reaching the surface. If we have present a sulphide ore with a siliceous gangue, the siliceous gangue is wetted preferentially by water and the sulphide particles by the oil. The patent of the Minerals Separation Company calls for the use of a fraction of one per cent of oil per ton of ore. An ore pulp usually runs about one ton of ore to four or five tons of water. When air is beaten into this mass, the particles of the sulphide ore go into the oil-water interface or into the oil itself, stabilizing the film because we then have practically armor-plated bubbles. The resulting froth can be scraped or shovelled off. Since most of the sulphide ore rises with the froth and since most of the siliceous gangue stays in the water, a very effective separation occurs. In most cases acidification of the solution and rise of temperature increase the effectiveness of the separation.

If the amount of air is insufficient, the oil may cause the ore particles to agglomerate and sink. This was patented by Cattermole; but it is not technically so successful as the frothing process. If the amount of air is excessive relatively to the ore, the number of bubbles will be so great that the ore particles cannot coat them sufficiently to armor-plate them and a fragile froth will be formed. This principle is made use of in the Callow process, in which air is introduced in fine bubbles at the bottom of the cell. These bubbles break as soon as they reach the surface and consequently the ore particles must be removed before they settle back. We can thus have clotted particles, armor-plated bubbles, or fragile bubbles, according to the conditions.

Coming back for a moment to emulsions, there is a wonderful chance for somebody to discuss whether the most important natural emulsion is milk or the rubber latex. Milk is necessary to life in the early stages; but pneumatic tires play a very important part later in life. Milk is an emulsion of liquefied butter fat in water which contains some other things. As obtained from the cow, milk is not very satisfactory when considered solely as an emulsion, because a more concentrated emulsion known as cream rises fairly quickly. If milk is passed through a homogenizer, the fat globules are broken up into smaller, more nearly uniform drops and we get an emulsion which remains unchanged when passed through an ordinary separator. If the cow had been more efficient mechanically, it is probable that skimmed milk would never have been discovered. When the milk emulsion is broken up by churning, the liquefied butter fat hardens into butter. The rubber latex is the milky juice from various kinds of rubber plants, chiefly trees and vines. It is an emulsion of liquid rubber in water which contains other things. The rubber emulsion can be broken down in a great many ways. On the plantations it is usually done by adding acetic acid. The liquefied rubber hardens just as did the liquefied butter fat and the product is raw rubber. One reason that we do not let milk sour in order to get butter is that the caseine comes down too. I do not know whether acid breaks the butter emulsion and whether one can get butter by adding vinegar to cream.

Raw rubber is not a satisfactory product in itself because it is too brittle when cold and too sticky when warm. It has to be vulcanized, which usually means heating with sulphur. Vulcanization is a problem of adsorption. There is only one compound of sulphur with rubber. It contains thirty-two per cent of sulphur, has the formula $C_{10}H_{16}S_2$, and is known as hard rubber or ebonite. Ordinary vulcanized rubber contains perhaps four per cent of combined sulphur and must therefore consist chiefly of raw rubber with hard rubber adsorbed on the surface of the raw rubber. Most rubber chemists dispute this conclusion because it is not possible to dissolve raw rubber out of vulcanized rubber with the solvents which will carry pure raw rubber into colloidal solution. This is not a serious objection however because we have already seen that a film of aluminum oxide keeps aluminum from being acted on by things which corrode pure aluminum.

Electrical engineers are interested of course in insulation problems. In addition to rubber we have three other well-known substances which are valuable, each in its own way: porcelain, artificial silk, and bakelite. The manufacture of all these involves colloid chemistry; but a discussion of these substances would take me far beyond any reasonable time limit. I hope, however, that I have succeeded in showing you that colloid chemistry is a subject which is of real interest to the electrical engineer.

The Wave Antenna

A New Type of Highly Directive Antenna

BY HAROLD H. BEVERAGE, CHESTER W. RICE, and EDWARD W. KELLOG

(*Continued from page 269*)

Case II. Signal at an Angle to Antenna, Zero Loss Antenna. So far we have considered only signal waves traveling in the direction of the antenna. To calculate the directive properties of the antenna, we must find the effect of a signal of the same wave length and intensity coming at an angle to the antenna. In the first place

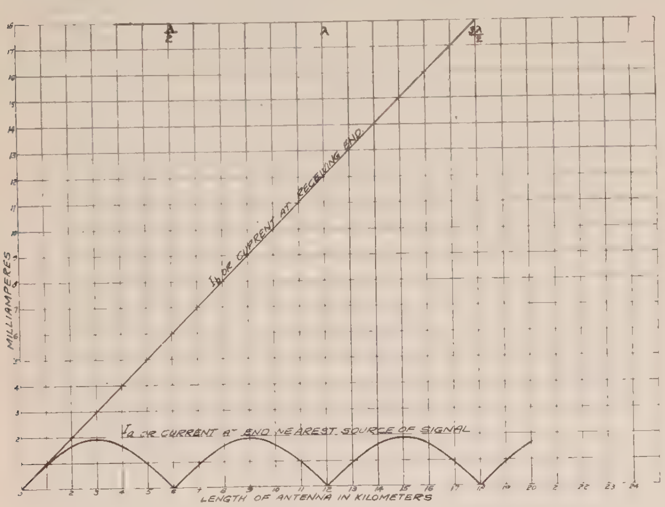

FIG. 29—RELATIVE CURRENTS AT THE TWO ENDS OF A WAVE ANTENNA

there will be a difference in the electromotive force E_0 induced in a unit length of wire. In Fig. 30A, we imagine ourselves looking down at two horizontal wires, each of unit length, situated in the midst of a signal wave whose magnetic lines are shown as dotted lines in the figure. Only the magnetic lines in a very thin layer

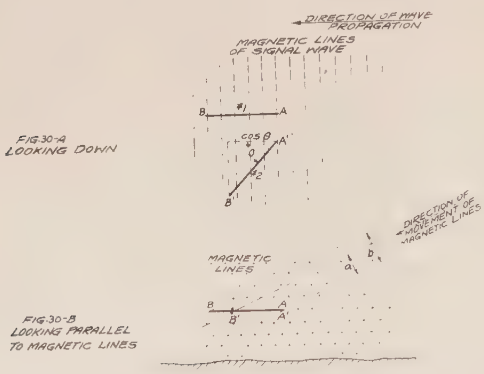

FIG. 30—EFFECT OF ANTENNA ANGLE ON INDUCED ELECTROMOTIVE FORCE PER UNIT LENGTH

immediately over the plane of the wires are shown. These magnetic lines have a horizontal movement indicated by the arrow, and a downward movement resulting from the forward tilt of the wave front. The horizontal movement causes no cutting of the conductor. Owing to the downward movement, the wires will be cut by all of the lines which cross them in the figure. The numbers of magnetic lines which cross wires No. 1 and No. 2 are in the ratio 1 to $\cos\theta$, and the induced electromotive force per unit length will be in the same ratio. Another point of view is illustrated in Fig. 30B, in which we imagine ourselves as looking at the ends of the magnetic lines, which now appear as dots. Here the same two wires are shown, and the actual direction of motion of the magnetic lines is indicated. Only those lines within the region a will cut wire No. 2 which appears in this projection as $A' - B'$, while all those in region b will cut No. 1, and the ratio of a to b is again $\cos\theta$. We shall therefore multiply by $\cos\theta$ to take account of the difference in induced electromotive force. That is to say if a signal coming in the direction of the antenna induces E_0 volts per kilometer, a signal of the same intensity coming from an angle θ to the antenna will induce $E_0 \cos\theta$ volts per kilometer.

The angle which the signal direction makes with the antenna also effects the time required for the wave front to pass over the antenna, and therefore affects the

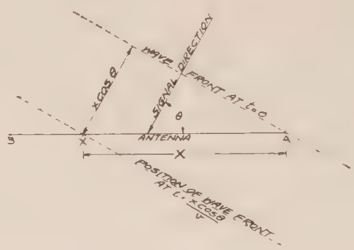

FIG. 31—EFFECT OF SIGNAL ANGLE ON TIME REQUIRED FOR WAVE TO TRAVERSE ANTENNA

relative phases of the electromotive forces induced in the different parts of the antenna. From the time the maximum electromotive force occurs at A to the time the same thing occurs at X the wave has only to travel a distance $x\cos\theta$ as indicated in Fig. 31, and this will require $\dfrac{x\cos\theta}{v}$ seconds, where v is the velocity of the signal wave. If the induced electromotive force at A is $e_a = (E_0\cos\theta)\sin\omega t$ then at X it will be

$$e_x = (E_0\cos\theta)\sin\omega\left(t - \frac{x\cos\theta}{v}\right) \qquad (\mathbf{13})$$

Comparing (**13**) with (**2**) we see that we now have the factor $\dfrac{v}{\cos\theta}$ where we had simply v, and where we had E_0 we now have $E_0\cos\theta$. Replacing v by $\dfrac{v}{\cos\theta}$ mean

changing u/v or n to $n \cos \theta$. Making these changes in (**11**) gives us, for the current due to a signal coming from a direction θ from the antenna.

$$I_b = \frac{E_0 \cos \theta}{Z \beta (1 - n \cos \theta)} \sin \frac{1}{2} \beta l (1 - n \cos \theta) \qquad (14)$$

If the signal is traveling in the direction of the antenna, $\theta = 0$, and $\cos \theta = 1$, and (**14**) becomes the same as (**11**). If the signal is from the opposite direction $\theta = 180$ deg., $\cos \theta = -1$ and (**14**) becomes the same as (**12**).

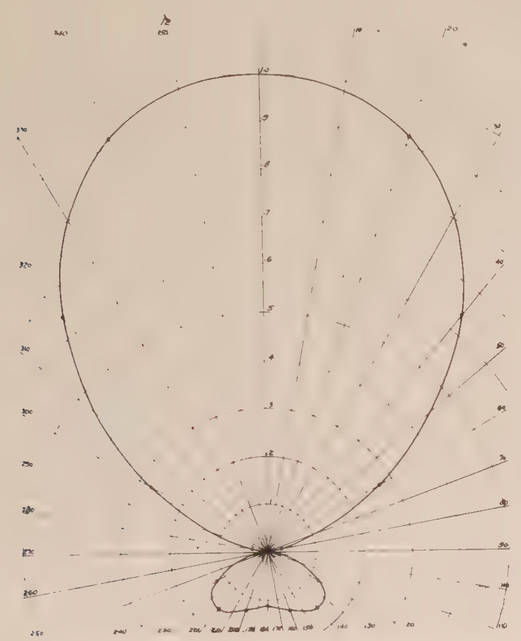

FIG. 32—DIRECTIVE CURVE OF WAVE ANTENNA. $\lambda = 15$ KM. $l = 12$ KM., $\alpha = .0$, $u = 0.8\,v$

Let us apply formula (**14**) to the calculation of the directive curve of the antenna whose currents for $\theta = 0$ and $\theta = 180$ deg. were determined in Fig. 28. The calculations are shown in Table I. Column IX, multiplied by E_0/Z would give the currents corresponding to the value assumed for E_0. To show directive properties, however, it is more satisfactory to give the current for any direction in terms of its ratio to the current which the same signal would produce if it came from the direction for which the antenna gives maximum reception. Thus column X gives the relative current strengths as found by dividing all the figures of column IX by the largest figure in the column which is 5.6 and corresponds to $\theta = 0$. Fig. 32 shows the directive curve of the antenna, obtained by plotting the relative currents as shown in column X radially at the corresponding angles.

Case III. Line Losses Considered. The factor *line attenuation* has so far been left out of account in order to simplify the problem. We assumed that the current at the end of the line, resulting from a wave which started at some point X, had the same strength as at X, although of different phase.

In the case of bare copper wire on poles, the errors due to ignoring line losses are not in general large enough to give misleading results. There are many instances however in which line losses are high or the antenna unusually long, where these effects cannot be neglected.

When there are no reflections to cause standing wave effects, the decrease in current strength as we go farther from the source is expressed by the relation $I_x = I_0 \epsilon^{-\alpha x}$, in which I_0 is the current strength at the source, I_x the current at a distance x from the source, and α is the "attenuation constant" of the line. A value of 0.05 per kilometer for α, means that the current decreases about 5 per cent with every kilometer which the wave travels.

In deriving equations (**4**) and (**5**), we regarded the point X in Fig. 26 as the source of waves on the antenna. We considered the current $d\, i_{ax}$ and $d\, i_{bx}$ at the ends of the line to have the same strength as the current $d\, i_x$ at x, since we were treating the case of a zero loss line. We now wish to consider a line on which there is attenuation, so the current $d\, i_{bx}$ at the end B, which is $(l - x)$ kilometers from the source, will be weaker than the current $d\, i_x$ at X, in the ratio $\epsilon^{-\alpha (l - x)}$, and the current $d\, i_{ax}$ at the end A, which is x kilometers from the source, will be weaker in the ratio $\epsilon^{-\alpha x}$. The phase relations as before are those corresponding the time differences $\frac{1 - x}{u}$ seconds and $\frac{x}{u}$ seconds required for waves to travel from X to B and X to A respectively. The current at X is $d\, i_x = \frac{e_x\, d\, x}{2\, Z}$, or substituting the value

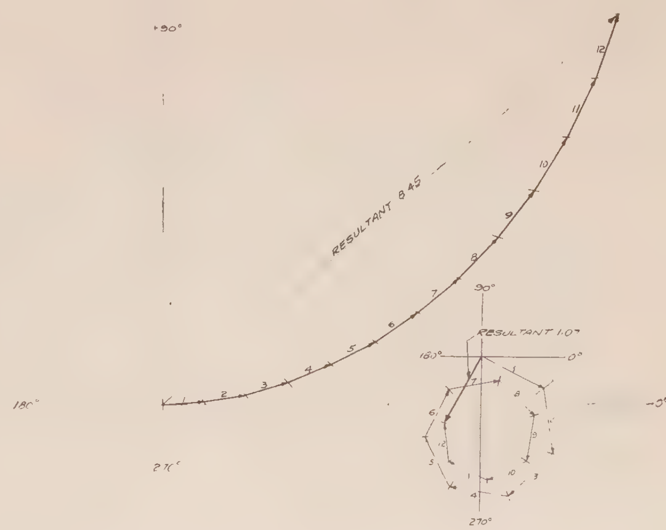

FIG. 33—DETERMINATION OF END CURRENTS FOR LINE WITH ATTENUATION

of e_x given in (**13**)

$$d\, i_x = \frac{E_0\, d\, x \cos \theta}{2\, Z} \sin \omega \left(t - \frac{x}{v} \right)$$

The current at B will be

$$d\, i_{bx} = \frac{E_0\, d\, x \cos \theta}{2\, Z} \epsilon^{-\alpha (l - x)} \sin \omega \left(t - \frac{x}{v} - \frac{l - x}{u} \right) \qquad (15)$$

TABLE I
DIRECTIVE CURVE OF WAVE ANTENNA ZERO ATTENUATION

$$I = \frac{E_0 \cos\theta}{Z\,\dfrac{\omega}{u}\left(1 - \dfrac{u\cos\theta}{v}\right)} \sin\frac{1}{2}\frac{\omega}{u}\, l\left(1 - \frac{u\cos\theta}{v}\right)$$

$$= \frac{E_0 \cos\theta}{Z\,0.524\,(1 - 0.8\cos\theta)} \sin 180 \text{ deg. } (1 - 0.8\cos\theta)$$

l = 12 km.
λ = 15 km.
u = 0.8 v.
α = 0

I	II	III	IV	V	VI	VII	VIII	IX	X
θ deg. Signal Angle	$\cos\theta$	$0.8\cos\theta$	$1 - 0.8\cos\theta$	$0.524\,(1 - 0.8\cos\theta)$	180 deg. $(1 - 0.8\cos\theta)$	Sin 180 deg. $(1 - 0.8\cos\theta)$	VII ÷ V	VIII × $\cos\theta$	Relative Current IX ÷ 5.6
0	1.00	0.8	0.2	0.105	36	0.588	5.6	5.6	1.00
20	0.94	0.752	0.248	0.13	44.8	0.704	5.4	5.08	0.91
40	0.766	0.612	0.388	0.203	70	0.94	4.62	3.54	0.63
60	0.50	0.40	0.60	0.314	108	0.951	3.02	1.51	0.27
80	0.174	0.139	0.861	0.450	155	0.423	0.94	0.164	0.03
90	0	0	1.00	0.524	180	0	0	0	0
100	−0.174	−0.139	1.139	0.596	205	−0.423	−0.71	0.124	0.022
120	−0.50	−0.40	1.40	0.734	252	−0.951	−1.29	0.645	0.115
140	−0.766	−0.612	1.612	0.845	290	−0.94	−1.11	0.85	0.152
160	−0.94	−0.752	1.752	0.918	315	−0.707	−0.77	0.724	0.129
180	−1.00	−0.80	1.80	0.945	324	−0.588	−0.622	0.622	0.111

TABLE II
DIRECTIVE CURVE OF WAVE ANTENNA

$$\text{Vector} \quad I_0 = \frac{E_0 \cos\theta\, \epsilon^{-j\frac{2\pi\cos\theta}{\lambda} l}}{2\,Z\left[\alpha + j\dfrac{2\pi}{n\lambda}(1 - n\cos\theta)\right]}\left\{1 - \epsilon^{-\left[\alpha + j\frac{2\pi}{n\lambda}(1 - n\cos\theta)\right] l}\right\}$$

λ = 12 km.
l = 12 km
u = 0.8 v.
α = 0.05
$\epsilon^{-\alpha l}$ = .55

Arranging Formula for Calculation of Magnitude and Substituting Numerical Values of Constants, we have

$$\text{Magnitude} \quad I = \frac{E_0}{2\,Z} \frac{\cos\theta}{\sqrt{(0.05)^2 + (0.654)^2\,(1 - 0.8\cos\theta)^2}} \left\{\begin{array}{l}\text{Vector Difference of 1.0 and 0.55}\\ \text{at Angle 450 deg. } (1 - 0.8\cos\theta)\end{array}\right\}$$

I	II	III	IV	V	VI	VII	VIII	IX	X	XI
θ Signal Angle	$\cos\theta$	$0.8\cos\theta$	$1 - 0.8\cos\theta$	$0.654\,(1 - 0.8\cos\theta)$	$\sqrt{(0.05)^2 + (0.654)^2(1 - 0.8\cos\theta)^2}$	450 deg. $(1 - 0.8\cos\theta)$	(Vector Difference) Graphical Solution	VIII ÷ VI	IX × $\cos\theta$	Relative Current X ÷ 8.14
0	1.00	0.80	0.2	0.131	0.140	90	1.14	8.14	8.14	1.0
20	0.940	0.752	0.248	0.162	0.169	112	1.31	7.75	7.3	0.896
40	0.766	0.613	0.387	0.253	0.258	174	1.55	6.0	4.6	0.565
60	0.50	0.40	0.6	0.393	0.396	270	1.14	2.89	1.45	0.178
80	0.1736	0.139	0.861	0.564	0.566	388	0.58	1.02	0.177	0.022
100	−0.1736	−0.139	1.139	0.744	0.745	513	1.51	2.03	0.35	0.0431
120	−0.50	−0.40	1.40	0.916	0.916	630	1.14	1.25	0.62	0.0762
140	−0.766	−0.613	1.613	1.055	1.055	726	0.45	0.427	0.326	0.040
160	−0.94	−0.752	1.752	1.146	1.146	789	0.96	0.838	0.78	0.0958
180	−1.00	−0.80	1.80	1.18	1.18	810	1.14	0.97	0.97	0.119

and the current at A will be

$$d\,i_{ax} = \frac{E_0\,d\,x\cos\theta}{2\,Z}\,\epsilon^{-\alpha x}\sin\omega\,(t - x/v - x/u) \quad (16)$$

The total end currents may be found by dividing the line into sections and drawing a series of vectors which represent the end currents resulting from the induced electromotive forces in the successive sections, as was done in Fig. 28. In the present case the vectors will differ progressively in length as well as in phase. Fig. 33 shows diagrams for finding the end currents for a signal direction parallel to the antenna. The conditions of the problem are the same as in the case of Fig. 28 except that for Fig. 33 an attenuation of 0.05 per kilometer is assumed. The corresponding vectors in the two figures have the same phase angles, but in Fig. 33 the vectors form a spiral instead of a circular arc.

The total end currents can be found by integrating equations (**15**) and (**16**) in their present form, but the work is simplified if we make use of vector notation.

In what follows, the symbols in bold faced type, such as **E** or **I** stand for vector quantities of the form $a + j\,b$, or its equivalent. For reference a summary is appended showing typical operations with vector quantities.

The induced volts per kilometer, $\mathbf{E}_a = \mathbf{E}_0\cos\theta$ at the end A of the antenna in Fig. 26, will be taken as the reference vector and the phase angle of any current or voltage means its angle of lead or lag with respect to $\mathbf{E}_a$.

The induced voltage per kilometer, $\mathbf{E}_x$ at the point X is of the same intensity as $\mathbf{E}_a$ but lags behind $\mathbf{E}_a$ by $\omega\dfrac{x\cos\theta}{v}$ radians. Therefore the vector of $\mathbf{E}_x$ is of the same length as that of $\mathbf{E}_a$ but is rotated backward, or clockwise $\omega\dfrac{x\cos\theta}{v}$ radians with respect to $\mathbf{E}_a$. This backward rotation is accomplished by multiplying by $\epsilon^{-j\omega\frac{x\cos\theta}{v}}$, so that

$$\mathbf{E}_x = \mathbf{E}_a\,\epsilon^{-j\omega\frac{x\cos\theta}{v}} = (\mathbf{E}_0\cos\theta)\,\epsilon^{-j\omega\frac{x\cos\theta}{v}} \quad (17)$$

The voltage induced in $d\,x$ kilometers of wire at X is $\mathbf{E}_x\,d\,x$, and this, acting through an impedance of $2\,\mathbf{Z}$ ohms produces a current at X of

$$d\,\mathbf{i}_x = \frac{\mathbf{E}_x\,d\,x}{2\,\mathbf{Z}} = \frac{\mathbf{E}_0\,d\,x\cos\theta}{2\,\mathbf{Z}}\,\epsilon^{-j\omega\frac{x\cos\theta}{v}} \quad (18)$$

The waves on the wire must travel $(l - x)$ kilometers from X to reach the end B of the antenna. Therefore compared with the current $d\,\mathbf{i}_x$ at X, the current $d\,\mathbf{i}_{bx}$ at B, is smaller in the ratio $\epsilon^{-\alpha(l-x)}$ and retarded in phase by the angle $\omega\dfrac{l-x}{u}$ radians. Hence

$$d\,\mathbf{i}_{bx} = d\,\mathbf{i}_x\,\epsilon^{-\alpha(l-x)}\,\epsilon^{-j\frac{\omega}{u}(l-x)}$$

Combining exponents and substituting β for ω/u we have

$$d\,\mathbf{i}_{bx} = d\,\mathbf{i}_x\,\epsilon^{-(\alpha+j\beta)(l-x)} \quad (19)$$

Substituting in this the value of $d\,\mathbf{i}_x$ shown in (**18**) we have

$$d\,\mathbf{i}_{bx} = \left\{\frac{\mathbf{E}_0\,d\,x\cos\theta}{2\,\mathbf{Z}}\,\epsilon^{-j\omega\frac{x\cos\theta}{v}}\right\}\epsilon^{-(\alpha+j\beta)(l-x)}$$

Combining exponents and collecting the x terms gives

$$d\,\mathbf{i}_{bx} = \frac{\mathbf{E}_0 d\,x\cos\theta}{2\,\mathbf{Z}}\,\epsilon^{-\left\{(\alpha+j\beta)\,l + (\alpha+j\beta-j\,\omega\frac{\cos\theta}{v}x\right\}} \quad (20)$$

The waves from X to A travel x kilometers on the wire, and are reduced in intensity in the ratio $\epsilon^{-\alpha x}$ and retarded in phase by $\omega\,x/u$ or $\beta\,x$ radians. Therefore

$$\begin{aligned} d\,\mathbf{i}_{ax} &= d\,\mathbf{i}_x\,\epsilon^{-\alpha x}\,\epsilon^{-j\beta x} \\ &= d\,\mathbf{i}_x\,\epsilon^{-(\alpha+j\beta)\,x} \\ &= \left\{\frac{\mathbf{E}_0\,d\,x\cos\theta}{2\,\mathbf{Z}}\,\epsilon^{-j\omega x(\cos\theta)/v}\right\}\epsilon^{-(\alpha+j\beta)\,x} \\ &= \frac{\mathbf{E}_0\,d\,x\cos\theta}{2\,\mathbf{Z}}\,\epsilon^{-(\alpha+j\beta+j\omega x(\cos\theta)/v} \end{aligned} \quad (21)$$

The total current $\mathbf{I}_b$ is the sum of all the currents $d\,\mathbf{i}_{bx}$, corresponding to all values of X, or in other words we integrate the expression (**20**) for $d\,\mathbf{i}_{bx}$ between the limits $x = o$ and $x = l$.

$$\mathbf{I}_b = \frac{\mathbf{E}_0\cos\theta}{2\,\mathbf{Z}}\,\epsilon^{-(\alpha+j\beta)\,l}\int_{x=0}^{x=l}\epsilon^{(\alpha+j\beta-j\omega x(\cos\theta)/v}\,d\,x$$

Performing the integration and substituting the limits gives

$$\mathbf{I}_b = \frac{\mathbf{E}_0\cos\theta\,\epsilon^{-(\alpha+j\beta)\,l}\,\{\epsilon^{(\alpha+j\beta-j\omega l(\cos\theta)/v} - 1\}}{2\,\mathbf{Z}\left(\alpha + j\beta - j\,\omega\dfrac{\cos\theta}{v}\right)}$$

This expression gives the value of $\mathbf{I}_b$, but it is more convenient for calculation if several changes are made in its form.

Putting $\epsilon^{-(\alpha+j\beta)\,l}$ inside the parenthesis gives

$$\mathbf{I}_b = \frac{\mathbf{E}_0\cos\theta\,\{\epsilon^{-j\omega l(\cos\theta)/v} - \epsilon^{-(\alpha+j\beta)\,l}\}}{2\,\mathbf{Z}\left(\alpha + j\beta - j\,\omega\dfrac{\cos\theta}{v}\right)}$$

Taking $\epsilon^{-j\omega l(\cos\theta)/v}$ out of the parenthesis gives

$$\mathbf{I}_b = \frac{\mathbf{E}_0\cos\theta\,\epsilon^{-j\omega l(\cos\theta)/v}\,\{1 - \epsilon^{-(\alpha+j\beta-j\omega l(\cos\theta)/v}\}}{2\,\mathbf{Z}\left(\alpha + j\beta - j\,\omega\dfrac{\cos\theta}{v}\right)}$$

Since $\omega/v = \dfrac{\omega\,n}{u} = \beta\,n$, we may substitute $j\,\beta\,(1 - n\cos\theta)$ for $j\,\beta - j\,\dfrac{\omega\cos\theta}{v}$, giving

$$I_b = \frac{E_0 \cos\theta\, \epsilon^{-j\,\omega\, l (\cos\theta)/v} \{1 - \epsilon^{-\{\alpha + j\beta(1 - n\cos\theta)\}\, l}\}}{2 Z [\alpha + j\beta(1 - n\cos\theta)]} \tag{22}$$

A more satisfactory form of the equation for purposes of calculation is obtained by separating the attenuation and phase angle factors in the expression $\epsilon^{-[\alpha + j\beta(1 - n\cos\theta)]\, l}$ and substituting $\frac{2\pi}{\lambda}$ for ω/v and $\frac{2\pi}{n\lambda}$ for β

This gives

$$I_b = \frac{E_0 \cos\theta\, \epsilon^{-j(2\pi l/\lambda)\cos\theta} \{1 - \epsilon^{-\alpha l}\, \epsilon^{-j\frac{2\pi l}{n\lambda}(1 - n\cos\theta)}\}}{2 Z \left[\alpha + j\frac{2\pi}{n\lambda}(1 - n\cos\theta)\right]} \tag{22a}$$

This is the complete expression for the current at the end B farthest from the signal source.

The total current at A is found similarly by integrating expression (21) for $d\, i_{ax}$ between the limits $x = o$, and $x = l$

$$I_a = \frac{E_0 \cos\theta}{2Z} \int_{x=0}^{x=l} \epsilon^{-(\alpha + j\beta + j\,\omega\, x(\cos\theta)/v)}\, dx$$

$$= -\frac{E_0 \cos\theta \{\epsilon^{-[\alpha + j\beta + j\,\omega\, l(\cos\theta)/v]} - 1\}}{2Z\left[\alpha + j\beta + j\frac{\omega\cos\theta}{v}\right]}$$

Substituting $j\ \beta(1 + n\cos\theta)$ for $j\ \beta + j\ \frac{\omega\cos\theta}{v}$ and putting the $-$ sign in the parenthesis, we have

$$I_a = \frac{E_0 \cos\theta \{1 - \epsilon^{-\{\alpha + j\beta(1 + n\cos\theta)\}\, l}\}}{2 Z [\alpha + j\beta(1 + n\cos\theta)]} \tag{23}$$

or

$$I_a = \frac{E_0 \cos\theta \{1 - \epsilon^{-\alpha l}\, \epsilon^{-j\frac{2\pi}{n\lambda} l(1 + n\cos\theta)}\}}{2 Z \left[\alpha + j\frac{2\pi}{n\lambda}(1 + n\cos\theta)\right]} \tag{23a}$$

Discussion of Equations. Equations (22) and (23) give the currents at the two ends of the antenna in their relative magnitude and phase relations with respect to the induced voltage per kilometer E_a, at the end A of the antenna. The assumptions throughout are that the antenna is straight and uniform and free from reflections at the ends, and that the signal wave causes no other electromotive forces in the circuit than that in the horizontal wire. The assumption that the induced electromotive force per unit length of conductor is the same in all parts of the antenna, and is independent of the amplitude of the wave on the wire, means that the reduction in intensity of the space wave by divergence or ground absorption has been neglected, and that no saturation effect has been considered. The absorption and divergence of the space wave may be estimated with fair approximation, and in most cases with antennas of moderate length, will be found to be negligible. No evidence of saturation has so far come to the writers' attention. In cases where the antenna has exceeded the length which gave maximum signal, the limit to the amplitude of the waves on the wire, has been set by the velocity difference or the line losses.

It will be noticed that (22) is the same as (23) except that the algebraic sign before the term $\cos\theta$ is reversed, and the factor $\epsilon^{-j\,\omega\, l(\cos\theta)/v}$ appears in the numerator of (22). The latter term has no effect on magnitude but effects the phase. If we should calculate the current at the end nearest the signal source by using formula (22) and assuming the signal to come from the opposite direction, or in other words take θ as 180 deg. instead of 0 deg., we would get the same numerical value for the current as though we had used equation (23), but the phase angle would be different because in (23) the phase is expressed with reference to the voltage produced by the signal at the end nearest the source of signal, whereas in using (22) and reversing θ to find the "back end" current, we refer the phase to that of the signal voltage at the end farthest from the signal source.

We are concerned with the question of phase only when currents from two or more sources are to be combined. For example, in calculating the effects of reflections or of voltages induced in the end verticals, it would be necessary to know the phase relations of the currents which are combined. Or when in order to put out a disturbance coming from a certain direction, we introduce in the receiving circuit a neutralizing current from another source, it is necessary to take account of the phases of the currents.

In making calculations of this kind we must watch the algebraic sign as well as the phase of the vector, and the following point should be kept in mind. An electromotive force is taken as positive if it acts in the direction A to B in Fig. 26, and a current is positive in this direction. Therefore, if we should find that the vectors for the back end and receiver end currents as figured by equations (23) and (22) point in the same direction, it would mean that the current at A is flowing from ground to antenna at the instant that the current at B is flowing from antenna to ground.

For figuring the simple directive curve of a wave antenna which does not call for determining the phase of the end currents, we may work entirely with equation (22) omitting the factor $\epsilon^{-j\,\omega\, l(\cos\theta)/v}$. The expression in the bracket is a vector difference and may be evaluated graphically or by use of the familiar formula for the third side of a triangle when two sides and the angle between them are given. We have two vectors, one having a length 1, and the other having a length $\epsilon^{-\alpha l}$, and the angle between them is $\beta(1 - n\cos\theta)\, l$ radians or $\frac{360\, l}{n\lambda}(1 - n\cos\theta)$ degrees. The vector difference is $\sqrt{1 + (\epsilon^{-\alpha l})^2 - 2\,\epsilon^{-\alpha l}\cos\frac{360\, l}{n\lambda}(1 - n\cos\theta)}$

The expression $\alpha + j\ \beta\ (1 - n \cos\theta)$ in the denominator must be given in terms of its vector length $\sqrt{\alpha^2 + \beta^2 (1 - n\cos\theta)^2}$. in order to calculate the current. Therefore, if the phase of the end current, relative to current or voltage in other parts of the antenna, is not sought, but only the magnitude of the end current, we may use the following formula, which is obtained by making the changes just mentioned in (**22**)

$$I_B = \frac{E_0 \cos\theta \sqrt{1 + (\epsilon^{-\alpha l})^2 - 2\,\epsilon^{-\alpha l} \cos \frac{360\, l}{n\,\lambda} (1 - n\cos\theta)}}{2\,Z \sqrt{\alpha^2 + \beta^2 (1 - n\cos\theta)^2}} \qquad (\mathbf{24})$$

This equation becomes equivalent to (**14**) if the line has no attenuation. If we set $\alpha = 0$ in (**24**), and substitute $\beta\, l$ for $\frac{360\, l}{n\,\lambda}$ we get,

$$I_B = \frac{(E_0 \cos\theta) \sqrt{2 - 2\cos\beta\, l\, (1 - n\cos\theta)}}{2\, Z\, \beta\, (1 - n\cos\theta)}$$

Making use of the trigonometric relation $1 - \cos a = 2\sin^2 1/2\, a$ we get under the radical in the numerator

Fig. 34—Chart for Evaluating $1 - \epsilon^{-\left\{\alpha + j\frac{2\pi}{n\lambda}(1 - u\cos\theta)\right\}}$

$$2 - 2\cos\beta\, l\, (1 - n\cos\theta) = 4\sin^2 \frac{1}{2}\beta\, l\, (1 - n\cos\theta)$$

and with this substitution the expression reduces to

$$I_B = \frac{(E_0 \cos\theta)\sin\frac{1}{2}\beta\, l\,(1 - n\cos\theta)}{Z\,\beta\,(1 - n\cos\theta)}$$

which is the same as (**14**).

Fig. 34 shows a chart for use in finding the value of the vector difference in the bracket of (**22**). The radius of the circle is taken as unity, ten centimeters being a convenient radius. Scale divisions from 0 to 1 are shown on one radius. From a point on this scale corresponding in value to $\epsilon^{-\alpha l}$, we measure the distance to a point on the circumference corresponding to the angle $\beta\, l\, (1 - n\cos\theta)$ radians or $\frac{360\, l}{n\,\lambda}(1 - n\cos\theta)$ degrees, and this measurement is the vector difference sought.

Let us apply formula (**22**) to the calculation of the directive curve of an antenna 12 kilometers long receiving a signal of 12 kilometers wave length, having an attenuation constant $\alpha = 0.05$ per kilometer, and a wave velocity $= 2.4 \times 10^5$ kilometers per second, or $n = 0.8$. The calculations are shown in Table II. Since the

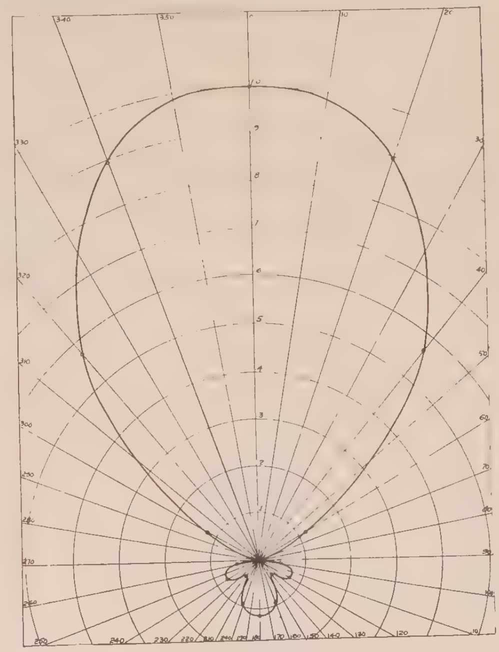

Fig. 35—Directive Curve of Wave Antenna. $\lambda = 12$ km., $l = 12$ km., $\alpha = 0.05$, $u = 0.8\, v$

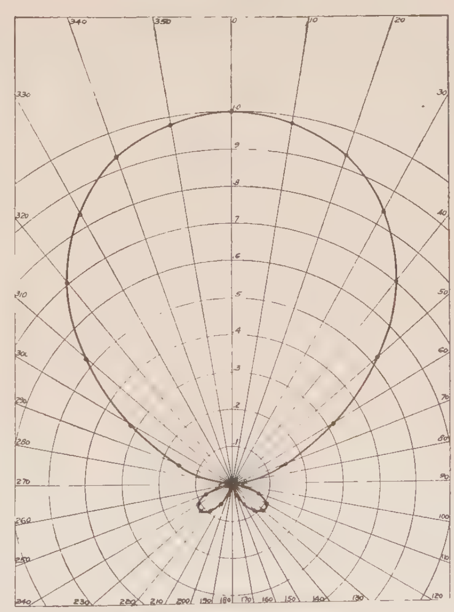

Fig. 36—Directive Current of Ideal Wave Antenna, One Wave Length Long. $\alpha = 0$, $n = 1$, $l = 12$, $\lambda = 12$

purpose of the directive curve is to show the relative receiver currents for different signal directions, the factor $\frac{E_0}{2\,Z}$ which is the same for all directions, is

omitted (or in other words assumed to have a value of 1) and the relative currents shown in column XI are obtained by dividing all the calculated currents of column X by the largest one of those, which corresponds to $\theta = 0$. The corresponding directive curve is shown in Fig. 35.

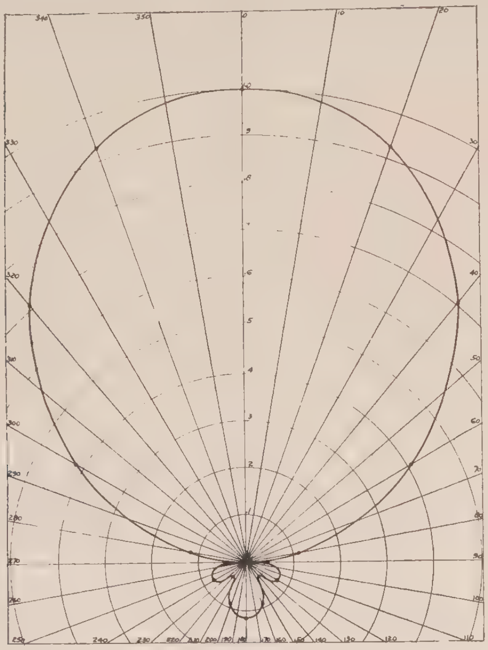

FIG. 37—DIRECTIVE CURVE OF WAVE ANTENNA ONE HALF WAVE LENGTH LONG. $\lambda = 12$ KM., $l = 6$ KM., $\alpha = 0.05$, $u = 0.8v$

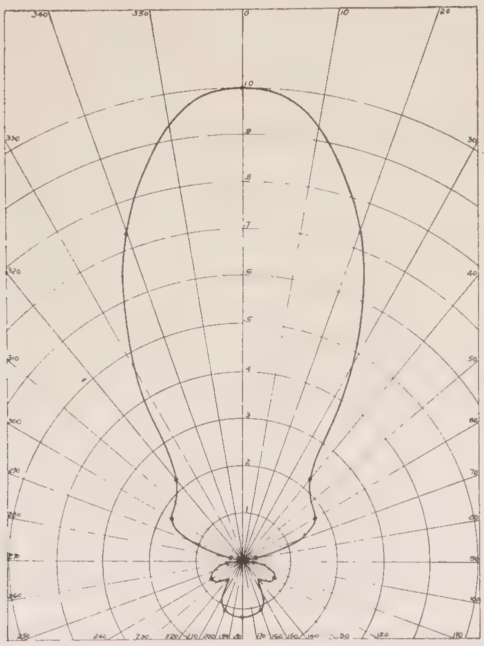

FIG. 38—DIRECTIVE CURVE OF WAVE ANTENNA TWO WAVE LENGTHS LONG. $\lambda = 12$ KM., $l = 24$ KM., $\alpha = 0.05$, $u = 0.8v$

Figs. 32 to 38 bring out the effects of length, velocity and attenuation on the directive properties of a wave antenna. The value 0.05 per kilometer for α, and 0.8 v for u, used in calculating Fig. 35, are mean values observed for long waves (7000 to 25,000 meters) on bare 0.102 inch (0.259 cm.) diameter copper wire supported on poles. Fig. 36 shows the directive curve for an antenna one wave length long on the assumption of zero attenuation and light velocity. By analogy with transmission line practise, we have referred to a wave antenna as "ideal" if it has zero attenuation and light velocity. While Fig. 36 was calculated for a 12 kilometer wave, the directive curve is applicable to any antenna a wave length long, and having full velocity and zero attenuation. The effect of length is shown by a comparison of Figs. 37, 35 and 38, which show the directive curves for antennas of the same constants and 1/2, 1 and 2 wave lengths long respectively. Fig. 39 compared with Fig. 35, shows the effect of reducing the velocity from .8 v to .6 v on a one wave length antenna, and Fig. 40 shows the effect of raising the velocity to 2 v. Fig. 41 is calculated for the same conditions as Fig. 35, except that for Fig. 41, the line losses are twice as high.

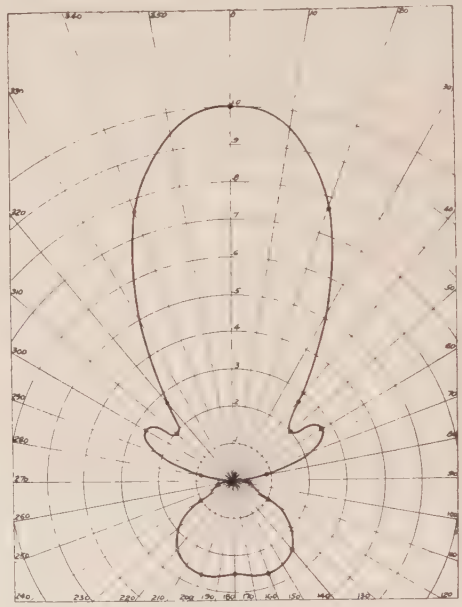

FIG. 39—DIRECTIVE CURVE OF LOW VELOCITY WAVE ANTENNA. $\alpha = 0.05$, $n = 0.6$, $l = 12$, $\lambda = 12$

Calculation of Phase Angle. Equation (**22**) is a vector equation which determines the magnitude of $\mathbf{I}_b$ and its phase relation with respect to the reference vector $\mathbf{E}_a$. It should be recalled that $\mathbf{E}_a$ is defined as the voltage induced per kilometer of antenna at the end "A". For convenience of discussion we will rewrite equation (**22a**) here

$$\mathbf{I}_b = \frac{\mathbf{E}_0 \cos\theta}{2\,\mathbf{Z}} \; \frac{\epsilon^{-j\frac{2\pi l}{\lambda}\cos\theta}\left\{1 - \epsilon^{-\alpha l}\,\epsilon^{-j\frac{2\pi l}{n\lambda}(1 - n\cos\theta)}\right\}}{\alpha + j\dfrac{2\pi}{n\lambda}(1 - n\cos\theta)} \qquad \textbf{(22a)}$$

In order to find the phase angle of the entire expres-

sion, we must first determine the phase angles of the individual vectors of which it is a product.

The first term $\frac{\mathbf{E}_0 \cos \theta}{2\,\mathbf{Z}}$ is a purely numerical multiplier with zero phase angle, when we assume $\mathbf{Z} = \sqrt{L/C}$ and take $\mathbf{E}_0$ as having zero phase angle.

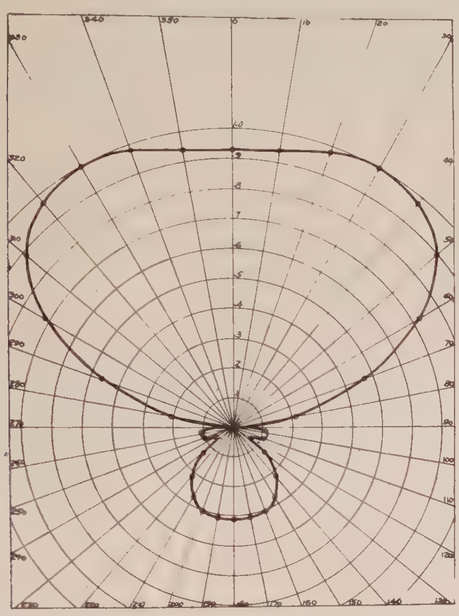

FIG. 40—DIRECTIVE CURVE OF WAVE ANTENNA WITH EXCESSIVE HIGH VELOCITY. $\alpha = 0.05$, $n = 2.0$, $l = 12$, $\lambda = 12$

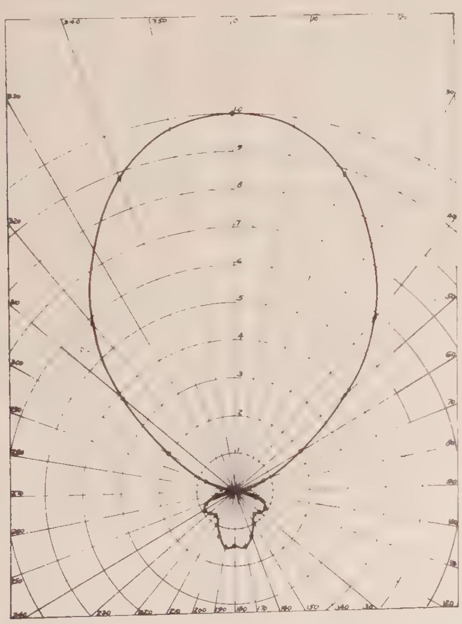

FIG. 41—DIRECTIVE CURVE OF WAVE ANTENNA WITH HIGH ATTENUATION. $\alpha = 0.10$, $n = 0.8$, $l = 12$, $\lambda = 12$

The term $\epsilon^{-j(2\pi l/\lambda)\cos\theta}$ is a unit vector having a phase angle $-\frac{2\pi l}{\lambda}\cos\theta$ radians or $-\frac{360\,l}{\lambda}\cos\theta$ degrees.

The bracket is the difference of two vectors, the first a unit vector with zero phase angle, and the second a vector having the absolute value $\epsilon^{-\alpha l}$ and the phase angle $-\frac{2\pi}{n\lambda}\,l\,(1 - n\cos\theta)$ radians or $-\frac{360°\,l}{n\lambda}\,(1 - n\cos\theta°)$ degrees. The graphical method of finding the magnitude and phase of this vector difference is shown in Fig. 42. Here the unit vector of zero phase angle $O\,A$ is drawn horizontally to the right. The vector $O\,B$ is then drawn with the length $\epsilon^{-\alpha l}$ and phase angle $-\frac{360°\,l}{n\lambda}\,(1 - n\cos\theta°)$. Then $B\,A$ is the vector difference sought. Its magnitude is determined by measuring the length $B\,A$ and its phase angle by extending $O\,A$ and $B\,A$ and measuring the angle between them.

The magnitude of the denominator is

FIG. 42—CHART FOR DETERMINING MAGNITUDE AND PHASE OF $\left\{1 - \epsilon^{-\alpha 2}\,\epsilon^{-j\frac{2\pi}{n\lambda}(1 - n\cos\theta)}\right\}$

$$\sqrt{\alpha^2 + \left[\frac{2\pi}{n\lambda}(1 - n\cos\theta)\right]^2}$$

and its phase angle $\tan^{-1}\frac{\frac{2\pi}{n\lambda}(1 - n\cos\theta)}{\alpha}$.

We have now determined the magnitude and phase angles of the quantities in the numerator and denominator of the expression for $\mathbf{I}_b$.

The magnitude of $\mathbf{I}_b$ is obtained by performing the arithmetical operations of multiplication and division using the absolute values of the vector quantities.

The phase angle of $\mathbf{I}_b$ is found by adding together the phase angles of the two vectors occurring as a product in the numerator and subtracting the phase angle of the vector in the denominator.

As an example let us find the magnitude and phase of the current $\mathbf{I}_b$ for an antenna of the following characteristics:

Wave length $\lambda = 12$ kilometers
Antenna length $l = 12$ kilometers
Attenuation constant $\alpha = 0.05$ per kilometer
Space wave velocity $v = 3 \times 10^5$ kilometer per second
Antenna wave velocity $u = 2.4 \times 10^5$ kilometers per second
Ratio $n = u/v = 0.8$ (numeric)

Ratio $\dfrac{\mathbf{E}_0}{2\,Z}$ assumed $= 1$ ampere per kilometer

Angle at which signal strikes antenna $= \theta$ degrees

If we substitute the above values in equation (**22a**) using the form (absolute magnitude) $\underline{/\text{Phase angle}}$, to designate a vector quantity, we obtain

$$\mathbf{I}_b = \frac{\{1\underline{/-360^\circ \cos\theta}\}\{1\underline{/0^\circ} - 0.55\underline{/-450^\circ(1-0.8\cos\theta)}\}\cos\theta}{\sqrt{(0.05)^2+[0.654(1-0.8\cos\theta)]^2}\ \underline{/\tan^{-1}(0.654\,(1-0.8\cos\theta)/0.05)}}$$

If we substitute various values of θ in this equation, we obtain the magnitude and phase of $\mathbf{I}_b$ as given in Table III. The calculation of magnitudes is taken from Table II, since the constants assumed are the same in the two cases.

Equation (**23**) or (**23a**) is the vector equation which determines the magnitude of $\mathbf{I}_a$ and its phase relation with respect to the reference vector $\mathbf{E}_a$. Equation (**23a**) is

$$\mathbf{I}_a = \frac{\mathbf{E}_0 \cos\theta\,\{1 - \epsilon^{-\alpha l}\,\epsilon^{-j\frac{2\pi}{n\lambda}l(1+n\cos\theta)}\}}{2\,\mathbf{Z}\left[\alpha + j\dfrac{2\pi}{n\lambda}(1+n\cos\theta)\right]} \qquad \textbf{(23a)}$$

If we substitute the assumed numerical values we obtain

$$\mathbf{I}_a = \frac{\{1 - 0.55\underline{/-450^\circ\,(1+0.8\cos\theta)}\}\cos\theta}{\sqrt{(0.05)^2+[0.654\,(1+0.8\cos\theta)]^2}\ \underline{/\tan^{-1}(0.654\,(1+0.8\cos\theta)/0.05)}}$$

If we substitute the various values of θ in this equation, we obtain the magnitude and phase angle of the current $\mathbf{I}_a$ given in Table IV.

Compensation of Back End Currents. An example of a problem which requires the calculation of both the magnitude and phase of the end currents is the determination of the directive curve of an antenna in which the current due to waves coming from a particular "back end" direction is "balanced out" by means of some of the current from the other end of the antenna.

Let us imagine there is an intense source of disturbance directly behind the antenna whose directive curve is given in Fig. 35, and for which we have just calculated the magnitude and phase of $\mathbf{I}_b$ and $\mathbf{I}_a$, and that we wish to neutralize the effect of this disturbance by an adjustment of the damping circuit at A.

From equation (**22**) or Table III we have for $\theta = 180$ deg., $\mathbf{I}_b = -0.968\ \underline{/+301\text{ deg.}}$

From equation (**23**) or Table IV we have for $\theta = 180$ deg., $\mathbf{I}_a = -8.15\ \underline{/-40\text{ deg.}}$

A fraction of $\mathbf{I}_a$ is to be reflected in such phase that it will cancel $\mathbf{I}_b$ in the receiver.

The current in receiver at B is $\mathbf{I}_b = -0.968\ \underline{/+301}$ deg.

The required compensating current at B is $\mathbf{I}_{cb} = -0.968\ \underline{/+301\text{ deg.}} - 180 = -0.968\ \underline{/+121\text{ deg.}}$

We have taken the compensating current as one half cycle or 180 deg. behind $\mathbf{I}_b$ in phase.

To allow for attenuation, and the time required for propagation from A to B, we must produce by the reflection at A, a current

$$\mathbf{I}_{ca} = \frac{-0.968}{\epsilon^{-\alpha l}}\ \underline{/+121^\circ + 450^\circ} = -1.76\underline{/+571^\circ}$$

The 450 deg. is the angle corresponding to the time of propagation or $360^\circ \dfrac{l}{n\lambda}$

Thus at A we have available a current $\mathbf{I}_a = -8.15\ \underline{/-40}$ deg. and wish to produce for the purpose of compensation, a current $\mathbf{I}_{ca} = -1.76\ \underline{/+571}$ deg.

This represents a phase advance of 611 deg.

We cannot reflect a wave before it arrives at the reflection point, which such a phase advance implies. A current, however, which is two complete cycles behind the desired value; that is, to say a current $-1.76\ \underline{/+571\text{ deg.}} - \underline{720\text{ deg.}}$ or $-1.76\ \underline{/-149\text{ deg.}}$ will give cancellation of all but the first two waves of the train, and this current which is 109 deg. behind $\mathbf{I}_a$ can be obtained by reflection. Experience has shown that in spite of the failure to neutralize the first two waves in a train, a very high degree of balance is obtainable, both on signals and static.

The terminal impedance required to give a specified reflection, may be determined from the vector relation

$$\mathbf{Z}_t = \mathbf{Z}\,\frac{\mathbf{I}_1 - \mathbf{I}_2}{\mathbf{I}_1 + \mathbf{I}_2} = \mathbf{Z}\,\frac{1 - \mathbf{I}_2/\mathbf{I}_1}{1 + \mathbf{I}_2/\mathbf{I}_1} \qquad \textbf{(25)}[15]$$

in which $\mathbf{Z}_t$ is the terminal impedance, $\mathbf{Z}$ the surge impedance of the line, $\mathbf{I}_1$ the current due to the oncoming wave and $\mathbf{I}_2$ the current due to the reflected wave. In the present case $\mathbf{I}_1$ is $\mathbf{I}_a$ and $\mathbf{I}_2$ is the desired $-1.76\ \underline{/-149\text{ deg.}}$

Then

$$\mathbf{I}_2/\mathbf{I}_1 = \frac{-1.76\underline{/-149^\circ}}{-8.15\underline{/-40^\circ}} = 0.216\underline{/-109^\circ}$$

$$= -0.070 - 0.204\,j$$

$$1 - \mathbf{I}_2/\mathbf{I}_1 = 1.070 + 0.204\,j$$

$$1 + \mathbf{I}_2/\mathbf{I}_1 = 0.930 - 0.204\,j$$

$$\frac{1 - \mathbf{I}_2/\mathbf{I}_1}{1 + \mathbf{I}_2/\mathbf{I}_1} = \frac{1.070 + 0.204\,j}{0.930 - 0.204\,j} = 1.055 + 0.450\,j$$

Substituting this value in (**25**) we have

$$\mathbf{Z}_t = Z\,(1.055 + 0.450\,j)$$

If the line surge impedance $\mathbf{Z}$ is 500 ohms, (with zero phase angle) the terminal impedance to give the desired

15. See page for derivation.

TABLE III

MAGNITUDE AND PHASE OF I_b

l = 12 Km. α = 0.05

λ = 12 Km. u = 0.8v.

I θ Signal Angle	II Cos θ	III 0.8 cos θ	IV $1 - 0.8 \cos\theta$	V $0.654\,(1 - 0.8\cos\theta)$	VI $\sqrt{(0.5)^2 + \{0.654\,(1 - 0.8\cos\theta)\}^2}$	VII -450 deg. $(1 - 0.8\cos\theta)$	VIII Vector Difference $\{1 - 0.55\,\underline{/\mathrm{VII}}\}$ from Diagram	IX VIII/VI	X IX cos θ Magnitude of I_b for $\frac{E^0}{2Z} = 1$	XI Relative Current X ÷ 8.15	XII Angle of VIII from Vector Diagram	XIII $\frac{0.654\,(1 - 0.8\cos\theta)}{0.05}$	XIV Tan $^{-1}$ XIII	XV XII − XIV	XVI − 360 deg. cos θ	XVII XV + XVI Phase Angle of I_b
0	1.000	0.800	0.200	0.131	0.140	−90°	1.14	8.15	8.15	1.000	+29°	2.62	69.1°	−40.1	−360	−400.1°
20	0.940	0.752	0.248	0.1625	0.1698	−112	1.30	7.65	7.18	0.880	+24°	3.25	72.9°	−48.9	−338	−386.9°
40	0.766	0.613	0.387	0.253	0.258	−174.0	1.55	6.02	4.61	0.565	+2 °	5.07	78.8°	−76.8	−276	−352.8°
60	0.500	0.400	0.600	0.393	0.396	−270.0	1.14	2.88	1.44	0.177	−29°	7.85	82.7°	−111.7	−180	−291.7°
80	0.174	0.139	0.861	0.563	0.565	−387	0.57	1.01	0.175	0.0215	+26°	11.30	85.0°	−59 0	−62.6	−121.6°
100	−0.174	−0.139	1.139	0.744	0.745	−512	1.51	2.03	−0.353	−0.0433	+10°	14.9	86.2°	−76.2	+62.6	− 13.6°
120	−0.500	−0.400	1.400	0.916	0.916	−630	1.14	1.245	−0.623	−0.0765	−29°	18.30	86.9°	−115.9	+180	+ 64.1°
140	−0.766	−0.613	1.613	1.055	1.055	−726	0.46	0.434	−0.333	−0.0408	+8°	21.10	87.3°	−79.3	+276	+ 196.7°
160	−0.940	−0.752	1.752	1.146	1.146	−788	0.95	0.826	−0.778	−0.0955	+33°	22.90	87.5°	−54.5	+338	+ 283.5°
180	−1.00	−0.800	1.800	1.176	1.176	−810	1.14	0.970	−0.970	−0.1185	+29°	23.6	87.60°	−58.60	+360	+ 301.4°

TABLE IV

MAGNITUDE AND PHASE OF I_a

l = 12 km. α = 05

λ = 12 km. u = 0.8v

I θ Signal Angle	II Cos θ	III 0.8 cos θ	IV $1 + 0.8\cos\theta$	V $0.654\,(1 + 0.8\cos\theta)$	VI $\sqrt{(0.05)^2 + \{0.654\,(1 + 0.8\cos\theta)\}^2}$	VII -450 deg. $(1 + 0.8\cos\theta)$	VIII Vector Difference $\{1 - 0.55\,\underline{/\mathrm{VII}}\}$	IX VIII/VI	X IX cos θ Magnitude of I_a for $E_0/2\,Z = 1$	XI Relative Current X ÷ 8.15	XII Angle of VIII from Vector Diagram	XIII $\frac{0.654\,(1 + 0.8\cos\theta)}{0.05}$	XIV Tan $^{-1}$ XIII	XV XII − XIV Phase Angle of I_a
0	1.000	0.800	1.800	1.176	1.176	−810°	1.14	0.97	0.97	0.1185	+29°	23.6	+87.6	−58.6°
20	0.940	0.752	1.752	1.146	1.146	−788°	0.95	0.826	0.778	0.0955	+33°	22.9	+87.5	−54.5°
40	0.766	0.613	1.613	1.055	1.055	−726°	0.46	0.434	0.333	0.0408	+8°	21.1	+87.3	−79.3°
60	0.500	0.400	1.400	0.916	0.916	−630°	1.14	1.245	0.623	0.0765	−29°	18.3	+86.9	−115.9°
80	0.174	0.139	1.139	0.744	0.745	−512°	1.51	2.03	0.353	0.0433	+10°	14.9	+86.2	−76.2°
100	−0.174	−0.139	0.861	0.563	0.565	−387°	0.57	1.01	−0.175	−0.0215	+26°	11.3	+85.0	−59.0°
120	−0.500	−0.400	0.600	0.393	0.396	−270°	1.14	2.88	−1.44	−0.177	−29°	7.85	+82.7	−111.7°
140	−0.766	−0.613	0.387	0.253	0.258	−174°	1.55	6.02	−4.61	−0.565	+2°	5.07	+78.8	−76.8°
160	−0.940	−0.752	0.248	0.1625	0.1698	−112°	1.30	7.65	−7.18	−0.880	+24°	3.25	+72.9	−48.9°
180	−1.000	−0.800	0.200	0.131	0.140	−90°	1.14	8.15	−8.15	−1.000	+29°	2.62	+69.1	−40.1°

neutralization would be 500 $(1.055 + 0.450\,j)$ or 527 ohms of non-inductive resistance and 225 ohms of inductive reactance.

Placing this impedance in the ground circuit at A will cause a similar reflection of all waves of the same length reaching A, whether due to a signal in line with the antenna or to a disturbance coming from a different direction. That is to say the reflected wave will in each case be 0.216 of the magnitude of the oncoming wave, and 109 deg. behind it in phase. When the reflected wave reaches the end B, its amplitude will be reduced to $0.55 \times 0.216 = 0.119$ of that of $\mathbf{I}_a$ and its phase will be further retarded by 450 deg. giving a total lag of 559 deg. behind I_a. Thus to find the directive curve of the antenna with the impedance described at A, we calculate I_a by equation (**22**), for each value of θ deg., determining the phase angle of $\mathbf{I}_a$ as well as its magnitude, multiply its magnitude by 0.119, retard its phase by 559 deg. and find the resultant when it is added vectorially to $\mathbf{I}_b$, calculated by formula (**23**) for the same value of θ deg.

(To be continued)

Application of Electric Motors for Driving Tube Mills

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Tube Mill Characteristics

THE greatest problem presented in the application of the electric motor for the individual drive of the tube mill is found in the fairly large torque required to bring it from rest up to its full operating speed. When once up to speed the load is practically constant, and only slight pulsations in the power requirements can be noticed.

Comprised of a rotating cylinder, the tube mill is filled to, or near, its center line with a grinding medium such as flint pebbles, cast iron balls, forged steel balls, and the material which is to be ground. The combination of the grinding medium and the material to be ground is usually termed "the charge."

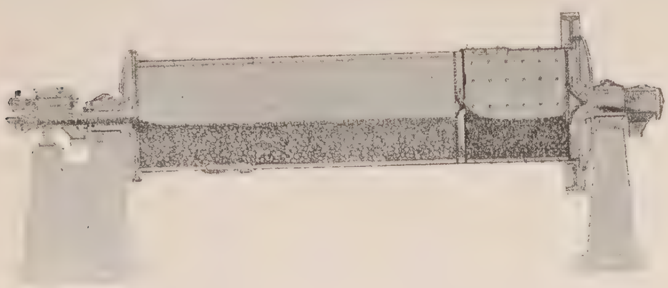

Fig. 1—Longitudinal Section of a Two-Compartment Tube Mill

A longitudinal section of a two-compartment mill at rest, Fig. 1, gives some idea as to the method of mounting or set-up, and the comparatively large mass that has to be moved in starting one of these mills. As there is a number of different forms of mills and methods of grinding, care has to be exercised in their differentiation, in order that correct analyses may be made.

One method of individual drive is through the medium of a reduction-gear unit, the main gear of which is an integral part of the tube mill proper, and a low-speed, direct-connected motor. Where dust and dirt are prevalent, the gears may be enclosed as in Fig. 12 and occasionally run in oil, although it is always advantageous to eliminate the foreign matter from the surrounding air if possible.

Another method of individual drive is through the medium of the gear unit, but a high-speed motor is used and belted to a countershaft.

Group drive is used extensively and in cases of this kind the tube mills are usually belted to a line shaft. Such a method of drive presents a different problem which may, however, be studied from a knowledge of the requirements of each individual mill, and the results then combined in such a manner that all overlapping will be properly considered.

In order to gain a somewhat more comprehensive idea as to the actual operating conditions, certain data were obtained from a small working model of a ball mill, one end of which was covered with glass so that the action of the grinding medium could be observed and photographed. No power data, however, were obtained from this model. The results from photographs are shown in Fig. 2 and are as follows:

Fig. 2A. Mill at rest and the surface of the ball charge in a horizontal position.

Fig. 2B. Mill at rest and the surface of the ball charge at an angle just below that of repose.

Fig. 2C. Mill in operation at critical speed, left hand rotation.

Fig. 2D. Mill in operation at critical speed, right hand rotation.

Fig. 2E. Mill rotating above critical speed.

The critical speed referred to is such that the bulk of the charge is carried to the highest possible point in the mill before falling, and without any of it being carried around by centrifugal force. This gives the ideal economical grinding speed if it were possible to run the mill in such a manner, but slight variations in materials, feed, level of charge, etc., are apt to create a condition where the charge begins to shower and do no effective grinding work by attrition. For these reasons the actual operating speed is somewhat less than the critical

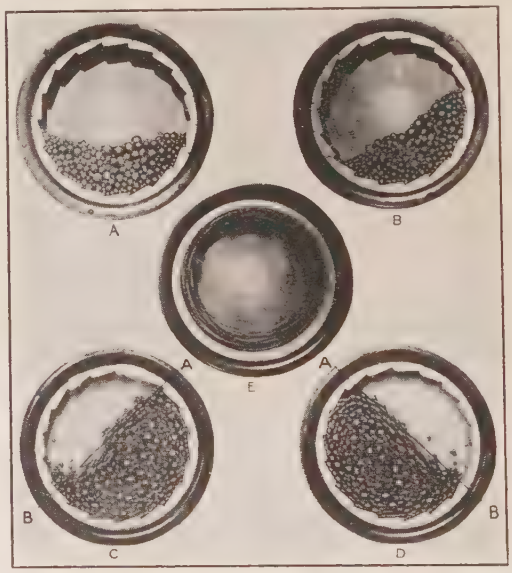

Fig. 2—Action of the Charge in a Ball Mill

speed, approximately 5 per cent to 7½ per cent, and may be closely approximated from

$$S_1 = 1600/d \qquad (1)$$

where S_1 = calculated correct operating speed of tube mill in rev. per min.

d = (diameter of mill in inches) – (thickness of lining × 2)

In starting a mill of this kind it is seen, that in addition to first overcoming the static bearing friction, it is also necessary actually to lift a certain amount of the charge and material, and accelerate the mill to a point corresponding to the line $A\ B$ Fig. 2B, and then eventually to the line $A\ B$ Figs. 2C and D.

Some idea as to the static starting torque required can be computed and checked against the figures given in Table 8 of Williamson's[1] paper referred to below. It is also possible to compute within fairly close limits, the speed-torque characteristics of the tube mill and these, compared with those of the electric motor, will show the limitations of the torque required for acceleration.

For the type of tube mill under consideration, the

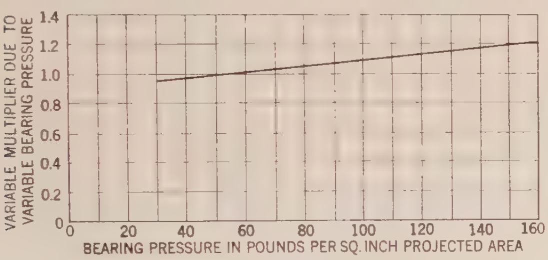

Fig. 3—Multiple for Coefficient of Bearing Friction

synchronous horse power to overcome the static bearing friction at the instant of starting is:

$$\text{h. p.} = 0.5\, C_p \times W_t \times r_b/12 \times \frac{2\,\pi \times S_1}{33{,}000} \qquad (2)$$

where h. p. = synchronous horse power, that is, the power required if the mill were actually running at its full speed, S_1.

C_p = variable multiplier due to variable bearing pressures. Take from curve Fig. 3.

W_t = total weight in pounds of all the revolving parts of the mill, including the grinding medium and the material to be ground.

r_b = radius in inches of the tube mill shaft in its bearings.

S_1 = calculated correct speed of mill. Take from formula (1).

0.5 = the coefficient of static friction for the bearings in these types of mills.

While the above coefficient of 0.5 seems high it must be remembered that ideal starting conditions can not be considered, also that the static friction of gear, pinion shafts and bearings, belt countershafts and bearings, etc. is included by this figure.

It is now possible to determine fairly accurately the two points A and B Fig. 4 of the speed power and the speed torque curves of the mill. The point A, which is the static torque required to overcome the standstill friction, can be determined from formula (2) as above, while the point B, which is the power required

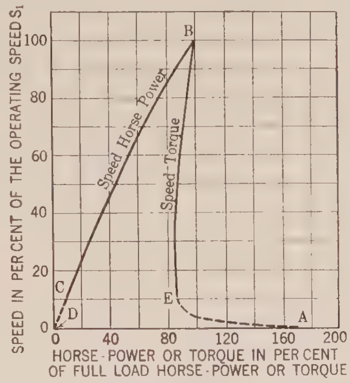

Fig. 4—Characteristic Speed Horse Power and Speed Curves of a 7 ft. by 22 ft. Plain Tube Mill with Flint Pebbles

to drive a tube mill for the dry grinding of limestone and clinker at its correct operating speed S_1 is:

$$P_1 = \{[K\,(W + W_m)] \times R/r + 0.00015\, w\} \times \frac{\cos \phi_1}{\cos \phi_2} \qquad (3)^2$$

For dry grinding only.

For wet grinding the power will be approximately 30 per cent less.

Where P_1 = horse power to operate mill at its correct operating speed S_1.

K = A constant = 0.00225 for a plain tube mill with flint pebbles.

= 0.0027 for a plain tube mill with ball pebbles compartment.

= 0.0030 for ball pebbles and compeb mills.

W = Weight of charge of pebbles or balls, in pounds.

W_m = Weight of material being ground in mill in pounds.

w = Weight of the revolving elements of the mill in pounds.

$\cos \phi_1$ = 30 deg. = 0.866.

$\cos \phi_2$ = To be taken from curve Fig. 6.

R = Distance in feet from center of mill to center of gravity of mass $W + W_m$.

r = $0.0177d$ and is the distance in feet from center of mill to center of gravity of mass $W + W_m$, assuming it comes to the center line of the mill.

1. Williamson. *Electric Motors in the Cement Industry*, A. I. E. E. Proc., November 1918.

2. Williamson's formula modified. loc. cit.

For variations from the calculated operating speed S_1, the power required to operate the tube mill will not vary as a straight line curve in direct proportion to the speed as might be indicated from formula (4), although the variation will not be very great. This is due to the fact that the angle of the grinding medium and the material to be ground varies from about 30 deg., from near zero speed to ¼ of the critical speed, to 40 deg. or 45 deg. at the critical speed. This is shown by reference to the various items of Fig. 2 and further elucidated by Fig. 5.

The actual horse power curve of the mill between the points B and D, Fig. 4, can, therefore, be closely determined from the following:

$$P_2 = \{[K (W + W_m)] \times R/r + 0.00015\, w\} \times S_2/S_1 \times \frac{\cos\phi_1}{\cos\phi_2} \qquad (4)[3]$$

3. Williamson's formula modified. loc. cit.

TABLE I

Plain Tube Mills with Flint Pebbles—Dry Grinding

Operating in Portland Cement Plants with 20 Mesh Feed, Grinding to 95 per cent Through 100 Mesh and 80 per cent Through 200 Mesh

Size of Mill	Operating Speed Actual $= S_2$	Operating Speed Calculated $= S_1$ Form (1)	W In Lb. Form (4)	*W_m In Lb. Form (4)	w In Lb. Form (4)	Horse Power Given in Williamson's Table 8		Calculated Horse Power by Form (2) & (4)		Bearing Sizes Inches	Total Wgt. In Lb. of Mill = Wt. Form (2)	Brg. Press. In Lb. Per Sq. in. Projected Area
						To Start	To Run	To Start Form (2)	To Run Form (4)			
3 ft. 6 in. x 20 ft.	40	40	9800	2980	15,720	60	35 to 40	55.2	39.8	10½ x 10½	28,500	129
†4ft. 0 in. x 20 ft.	35	34.8	11,600	3530	24,480	70	45 to 48	92	45.3	16 x 16	39,610	77.5
4 ft. 6 in. x 22 ft.	31	30.8	14,500	4400	33,735	85	55 to 60	109.5	57.4	15 x 15	52,635	117
5 ft. 0 in. x 22 ft.	28	27.6	20,000	6080	39,420	120	75 to 80	122.8	77.9	15 x 18	65,500	121
5 ft. 6 in. x 22 ft.	26	25	24,000	7300	47,581	150	95 " 100	140.5	95.3	15 x 18	78,881	146
6 ft. 0 in. x 22 ft.	24	22.9	29,000	8820	57,322	185	115 " 125	201	115.5	20 x 18	95,142	132
7 ft. 0 in. x 22 ft.	20	19.5	39,000	11,850	71,290	250	160 " 175	252	152	20 x 18 24 x 18	122,140	154

*$W_m = 0.304\, W$

The Above Figures are Based on the Charge & Material Level Being Carried at the Center Line of the Mill and Therefore $R = r$

Thickness of Shell Lining = 1 in. Iron

†Special Mill

TABLE II

Ball-Peb and Compeb Mills—Dry Grinding

Operating in Portland Cement Plant with 20 Mesh Feed, Grinding, to 95 per cent through 100 Mesh and 80 per cent through 200 Mesh

Size of Mill	Operating Speed Actual $= S_2$	Operating Speed Calculated $= S_1$ Form (1)	W In Lb. Form (4)	*W_m In Lb. Form (4)	w In Lb. Form (4)	Horse Power Given in Williamson's Table 9		Calculated Horse Power by Form (2) & (4)		Bearing Sizes Inches	Total Wgt. In Lb. of Mill = Wt. Form (2)	Brg. Press. In Lb. Per Sq. in. Projected Area
						To Start	To Run	To Start Form (2)	To Run Form (4)			
5 ft. 0 in. x 5 ft.	28	28.1	9000	1090	21,910	..	52	54.4	49.6	15 x 18	32,000	59.3
5 ft. 0 in. x 10 ft.	28	28.1	18,000	2180	28,320	..	96	87.7	96.5	15 x 18	48,500	90
5 ft. 0 in. x 15 ft.	28	28.1	27,000	3270	35,230	..	143	155	143.5	20 x 20	65,500	82
5 ft. 0 in. x 22 ft.	28	28.1	39,600	4800	44,862	..	210	244	209	24 x 20 20 x 20	89,262	106
5 ft. 6 in. x 5 ft.	26	25.4	11,000	1330	24,970	..	62	58.5	62.3	15 x 18	37,300	69.2
5 ft. 6 in. x 10 ft.	26	25.4	22,000	2660	34,190	..	118	99.8	121.7	15 x 18	58,850	109
5 ft. 6 in. x 15 ft.	26	25.4	33,000	4000	41,881	..	177	174	180.7	20 x 20	78,881	98.5
5 ft. 6 in. x 22 ft.	26	25.4	48,500	5870	52,055	..	260	270	264	24 x 20 20 x 20	106,425	121
6 ft. 0 in. x 5 ft.	24	23.2	13,000	1570	32,630	..	75	89.3	74.7	20 x 18	47,200	65.7
6 ft. 0 in. x 10 ft.	24	23.2	26,000	3150	40,850	..	143	140.5	144.7	20 x 18	70,000	97.2
6 ft. 0 in. x 15 ft.	24	23.2	39,000	4720	49,780	..	215	200	215	20 x 18	93,500	130
6 ft. 0 in. x 22 ft.	24	23.2	57,200	6920	61,030	..	316	321	314	24 x 20	125,150	130.5
7 ft. 0 in. x 5 ft.	20	19.75	18,000	2180	42,320	..	101	114	103	24 x 18 20 x 18	62,500	79
7 ft. 0 in. x 10 ft.	20	19.75	36,000	4350	52,650	..	199	181	200	24 x 18 20 x 18	93,000	117.5
7 ft. 0 in. x 15 ft.	20	19.75	54,000	6540	63,160	..	298	258	298	24 x 18 20 x 18	123,700	156
7 ft. 0 in. x 22 ft.	20	19.75	79,200	9590	76,410	..	438	369	434	24 x 24	165,200	143.5
8 ft. 0 in. x 5 ft.	18	17.2	23,500	2840	49,960	.	130	129	125.7	24 x 24	76,300	66.2
8 ft. 0 in. x 10 ft.	18	17.2	47,000	5700	61,300	..	257	205.5	262	24 x 24	114,000	99
8 ft. 0 in. x 15 ft.	18	17.2	70,500	8530	73,946	..	386	292	391	24 x 24	152,976	133
8 ft. 0 in. x 22 ft.	18	17.2	103,300	12,600	90,130	..	567	458	563	28 x 28	206,030	132

*$W_m = 0.121\, W$ Thickness of Shell Lining = 1½ in.

The Above Figures are Based on the Following

5 ft. 0 in. Dia. Mill—Charge & Material Level Within 6″ of Center Line of Mill—1800 Lb. Initial Charge Per ft. Lgth. of Mill $R = 1.28$ $r = 1.01$

5 ft. 6 in. " " " " " " " 7″ " " " " " " 2200 " " " " " " " $R = 1.43$ $r = 1.115$

6 ft. 0 in. " " " " " " " 8″ " " " " " " 2600 " " " " " " " $R = 1.57$ $r = 1.22$

7 ft. 0 in. " " " " " " " 10″ " " " " " " 3600 " " " " " " " $R = 1.87$ $r = 1.43$

8 ft. 0 in. " " " " " " " 11″ " " " " " " 4700 " " " " " " " $R = 2.13$ $r = 1.645$

Where symbols as used are the same as in formula (3) and

Where P_2 = horse power to operate mill at any speed S_2

S_1 = calculated correct speed of mill. Take from formula (1).

S_2 = speed in rev. per min. for which P_2 is to be determined.

For plain tube mills with flint pebbles, the results as checked against Table 8 in Williamson's paper, are as shown in Table 1 while for ball pebbles and compeb mills, the results compared to a representative number

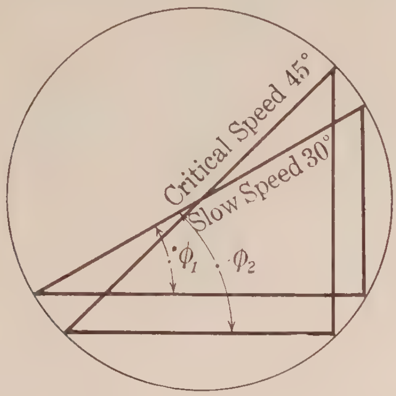

Fig. 5—Variation in Angle of Charge on a Tube Mill

from Williamson's Table 9, are as shown by Table II. These show some rather remarkable things. While it is to be noted that the running power requirements can be calculated within very close limits, the static starting-torque requirements follow no set rule when compared to the normal running torques of the various mills. The general idea that a tube mill requires 125 per cent to 150 per cent of normal torque for starting does not, therefore, always hold true. It is obvious that the 7 by 15 ft. ball pebble mill, Table 2, having practically the same weight and having the same size bearings and running at the same speed as the 7 × 22 ft. flint pebble mill, Table 1, should have the same static starting torque. While the ball pebble mill requires 298 h. p. to operate it at normal speed, the flint pebble mill requires only 152 h. p., but other things being equal, there is no reason for specifying a motor with characteristics suitable to start the former mill with 1.50 × 298 = 447 synchronous h. p. torque, and the latter with only 1.50 × 152 = 228 synchronous h. p. torque. The static torque requirements will be the same in either case. The acceleration torques, however, will be entirely different.

Inasmuch as torque is:

$$T = \frac{P_2 \times 33{,}000}{2\pi \times S_2} \tag{5}$$

Where T = Torque in pounds at 1 ft. radius.

P_2 = h. p. for speed S_2.

S_2 = Speed for h. p. P_2.

A large part of the speed torque of the mill can be determined from that part $B\,C$ of the curve $B\,C\,D$ and is as shown by partial curve $B\,E$ of the curve $B\,E\,A$, Fig. 4. These curves indicate that the horse power required to drive any given mill varies fairly closely in direct proportion to the speed, and the torque also remains fairly constant.

Once the static is overcome and the tube mill is started, the torque required drops off very quickly and very considerably so that that part of the torque curve from E to A, Fig. 4, which is not of any great importance except in establishing the point A, can readily be assumed, and is, therefore, shown by the dotted line. For the sake of convenience, this part of the torque curve can also be interpreted in terms of synchronous rather than the actual horse power for which the dotted portion $C\,D$ of curve $B\,C\,D$ is drawn. The complete power curves of any given tube mill can thus be established and calculated within reasonable limits.

Application of the Slip-Ring Type Induction Motor to the Tube Mill

The speed torque curve of the slip-ring type and the squirrel-cage type of polyphase induction motor is well known, so that by super-imposing the starting curves of any given size and type of motor on the curves of any given size of tube mill, a good idea of the combined conditions pertaining to starting may be obtained.

Consider first the case of a slip-ring type induction motor starting a tube mill, and let it be assumed that the size of the motor is such as to correspond to the figures as given in either Table I or Table II under the column of horse powers required to run any given mill.

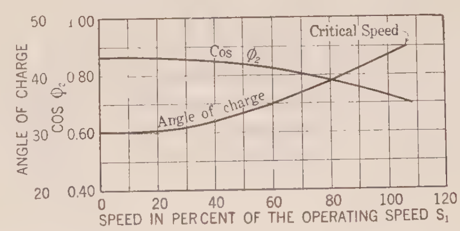

Fig. 6—Variation in Angle of Charge with Respect to the Speed

This means that the motor size is not too small nor yet too large for any particular mill that it is to operate.

Referring then to Fig. 7 the curve $B\,E\,A$ indicates the speed-torque curve of any given tube mill, calculated in accordance with the above methods.[4] Superimposed on this curve are the speed-torque curves of the induction motor, which is of the correct size to drive this given mill. These motor curves are indicated by the curves $D\,C$, $D\,A$, $D\,F$, $D\,G$, $D\,H$, $D\,I$, $D\,J$ and $D\,K$ and represent the different positions of the con-

4. Note that while this curve indicates an initial static torque of 150 per cent, this is not the true characteristic, as explained previously, of every tube mill.

troller in starting in a regular sequence of 1, 2, 3, 4, 5, 6, etc.

If the secondary resistance unit is designed to give the motor a speed-torque curve on the first starting position of the controller of *D C*, it is apparent that the motor will not develop enough torque to start the mill.

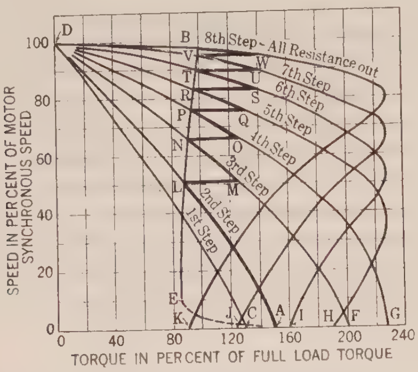

Fig. 7—Slip-Ring Induction Motor Starting a Tube Mill

It is, therefore, necessary to go to the second control position which develops just enough torque to turn the mill. It is thus seen that the control resistance units, in order to be correct, should be designed to meet the characteristics of any given tube mill so that the motor will start the mill on the first controller step.

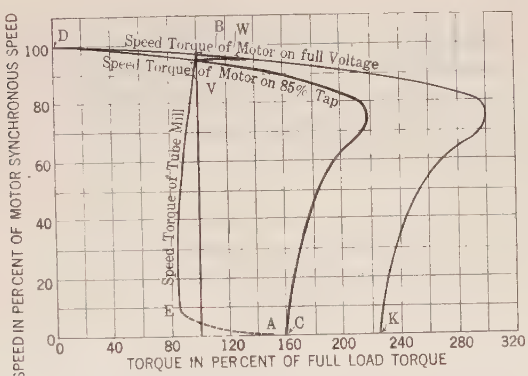

Fig. 8—Squirrel-Cage Induction Motor Starting a Tube Mill

The resulting speed torque curve can then be represented by the zig-zag line *A L*.

Application of the Squirrel-Cage Induction Motor to the Tube Mill

In comparison to this, consider now the starting conditions of a squirrel-cage motor of the necessary size and capacity to start and run the same tube mill, to which the slip-ring motor was directly connected. Assume that this squirrel-cage motor is termed a high-torque motor and that it will develop 225 per cent of full-load torque if it be possible to connect it directly to the line. Assume also, that the potential starter is connected so that the motor will be connected to the highest tap, 85 per cent, during the initial starting operation. The conditions are as shown by Fig. 8 and the resulting speed-torque curve is represented by the zig-zag line *C V W B*.

Comparison of Slip-Ring Versus Squirrel-Cage Motor Applications to the Tube Mill

The comparative speed torque resultant curves of slip-ring and squirrel-cage motors are as shown by Fig. 9. A perusal of these curves shows that with the slip-ring motor, the starting is accomplished in seven distinct and separate steps (more or fewer steps can be used because this depends entirely on the control

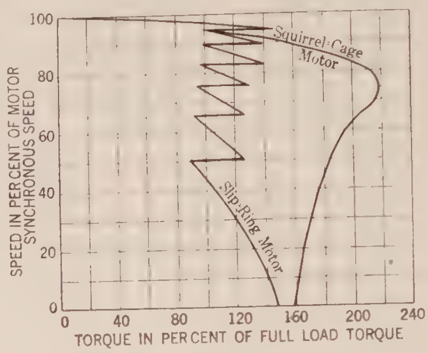

Fig. 9—Comparative Torque of Slip-Ring and Squirrel-Cage Induction Motors Starting a Tube Mill

apparatus) while with the squirrel-cage motor, the starting is accomplished in only two separate steps. It is obvious that this latter method can not help but create a condition which is not ideal. The ideal starting arrangement would be such as to provide a large number of infinitesimally small starting positions, each of which would create maximum torque with minimum current and high power factor. These are conditions exactly contrary to the squirrel-cage motor and potential starter control, for here there are few

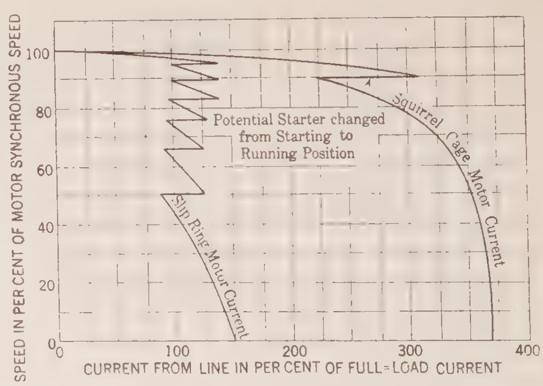

Fig. 10—Comparative Currents of Slip-Ring and Squirrel-Cage Motors Starting a Tube Mill

starting points which create minimum or the necessary torque with maximum current at extremely low power factor.

The comparative starting currents of the two different types of motors and for the particular case in point, are shown by Fig. 10. From this it is readily seen that with the slip-ring type motor the current taken from the line never exceeds 150 per cent of the full-load line current while with the squirrel-cage motor the current taken from the line reaches a maximum of 370 per cent of the full-load line current. When it is considered that the power factor of the slip-ring motor under these conditions will always be fairly close to the actual full-load running power factor of the motor

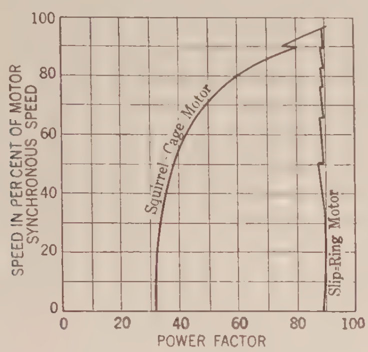

Fig. 11—Comparative Power Factors of Slip-Ring and Squirrel-Cage Induction Motor Stating a Tube Mill

and that of the squirrel-cage motor will be as low as 35 per cent to 50 per cent throughout most of the starting period, Fig. 11, it can readily be appreciated that the latter type of motor creates an unreasonable demand for current from the line. In addition, the unusually large starting currents set up electrical mechanical stresses in the motor itself and mechanical stresses in the drive and tube mill, which are necessarily derogatory because the larger the currents the greater these stresses and shocks will be. It is not generally considered good practise to use a squirrel-cage motor, in sizes of 50-h. p. and above, where the starting conditions necessitate the use of as high a starting tap as 85 per cent, especially when the machine has a high-torque rotor.

It is also apparent that due consideration should be given to the fact that the high-torque squirrel-cage motor will operate at lower efficiency than the slip-ring motor. In large installations this can be capitalized into many thousands of dollars.

Application of the Synchronous Motor to the Tube Mill

The use of the low-speed induction motor for driving the tube mill has had the particular disadvantage in that it operates at low power factor. For any given frequency the lower the speed, the lower the power factor will be. This is an inherent feature of the induction motor that can not be overcome commercially. On systems where the power demand for the motors is large it generally results in increased rates if power is being bought, or where power is generated in the local plant itself, in loading-up the equipment with a large wattless component which limits the true capacity of the generator.

These various points are the chief factors which have led to the use of the synchronous motor in quite a number of new installations which have been put into service in the last one or two years. It is also a fact that, if the speed required becomes low enough to necessitate the use of a large number of poles in the motor, a point is reached where the first cost, or outlay, required for the synchronous motor and all its complements is actually less than that required for the slip-ring type induction motor and all of its complements.

The self-starting synchronous motor while similar in a way to the squirrel-cage induction motor, in that it has poor starting torque characteristics, differs from it in that when suitably applied, it can be made to operate at unity power factor or to introduce leading currents in the power system to which it is connected.

On account of the characteristics of the synchronous motor not being particularly well adapted to overcoming large static loads and accelerating them, it has been deemed advisable to interpose a clutch, Fig. 12, between the motor and the tube mill, provided the motor is not made especially large for power factor correction reasons as well as to take care of the load without a clutch. As the requirements under these conditions merely necessitate the motor overcoming its own static

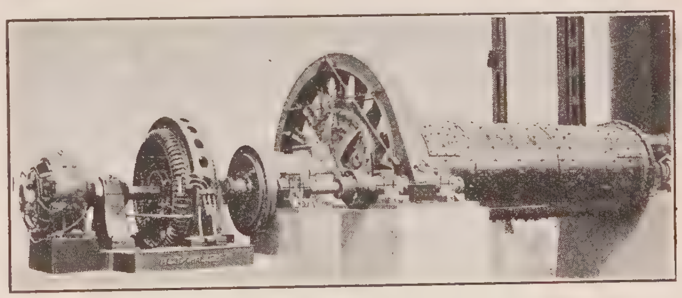

Fig. 12—Synchronous Motor Driving a Tube Mill Through a Magnetic Clutch and Gear Reduction Unit

and idle losses, it does not necessarily have to have high starting torque features, although this class of motor can readily be made with characteristics comparing favorably with those of the squirrel-cage induction motor. If, however, the action of the clutch is such as to grab the load suddenly, and this is not advisable on account of the electrical and mechanical shocks resulting therefrom, it is necessary that the synchronous motor have high pull-out torque characteristics. The ideal condition is to have the clutch with a definite time-element action during the starting period and as such it will impose no undue shocks, or require abnormal pull-out torque characteristics on the part of the driving motor.

Transient Conditions in Electric Machinery

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Review of the Subject:— *The vector method is just as useful in solving problems involving transient conditions in electric circuits as it has proved to be when the currents and potentials are steady sinusoids. As far as the writer is aware, the vector method for determining transients in rotating electric machines was first used by L. Dreyfus. Previously the method had been applied to fixed combinations of resistances, inductances and capacitances by Kennelly and others.*

By making certain assumptions that are, however, quite reasonable in many cases, the transient currents in nearly all of the common types of electric machinery are damped sinusoids. Fortunately the damping is exponential and is thus readily accounted for. It is interesting to trace the development of the method. In the solution of all problems in direct currents the potentials, currents, and circuit constants are real numbers. In the corresponding problem in which the applied potentials are steady sinusoids, these quantities are all represented by complex numbers. In all other respects the working out of the solution is identical with that followed in the direct-current case. When the currents are damped sinusoids, they and the potentials and the circuit constants can still be represented by complex numbers. There is this difference, however; the vectors which represent the currents and potentials shrink exponentially as they rotate and the values of the circuit constants depend not only upon the frequency of the current, but also upon its rate of shrinking. Again the solution of any problem follows the same procedure that would the corresponding one in which the currents are steady sinusoids. In both the steady and damped sinusoidal cases the circuit constants depend upon the angular velocity of the vectors which represent the currents. In the former, the angular velocity is purely imaginary while in the latter it is complex, the real part being the rate at which the current vector shrinks and the imaginary portion, its angular velocity. In electric machinery in which rotating magnetic fields are produced, these fields shrink exponentially as they rotate when the currents are damped sinusoids. If these rotating magnetic fields are represented by vectors, the vectors will have a complex angular velocity just as do the currents. The e. m. f. which is produced by a steady sinusoidal variation of flux lags the flux by 90 degrees, whereas if the flux variation is a damped sinusoid, the angle of lag is less than 90 degrees, depending upon the damping. The mathematical relation, however, is the same, viz., the e. m. f. is proportional to the negative of the product of the flux and its angular velocity. It is then readily appreciated that the form of the solution for the transient state is the same as that which is used for the steady state. Before the method can be expected to give as accurate results as are obtained when predicting the steady operation, considerable experimental data must be obtained in order to determine the best methods of measuring the necessary constants, for these may be somewhat different during the transient period than during steady operation.

* * * * * * * *

THE problem of calculating the transient currents in alternating-current apparatus has rightly been considered a difficult one. Fortunately, the difficulty lies not so much in the problem itself as in the inadequacy of the mathematical treatment that has been employed. If a vector method of analysis is used, very great difficulties are removed. This was first appreciated by the author early in 1921 while studying the paper "Short-circuit Current of Induction Motors and Generators" by Doherty and Williamson. Later it was found that the vector method had already been developed by L. Dreyfus.[1] Notwithstanding this previous publication, the subject was considered of sufficient importance to warrant the presentation of this paper.

As is the case with many other complex problems, the method of attack is presented most clearly when certain ideal conditions are assumed. These conditions are that the resistances and inductances are constant and, in the case of rotating machines, that the speed is constant and that the space distribution of air-gap flux is sinusoidal. After one is familiar with the method in its simplest form, it may be possible to introduce refinements which will account for iron losses, variable permeability and harmonics.

The form of the transient current in any system of mutually inductive circuits is determined by the differential equations of the fall in electric pressure through them. With the foregoing assumptions in regard to the ideal character of the electric circuits, the differential equations which apply to most of the common types of direct and alternating-current machinery may be reduced to the form which is described as "linear with constant coefficients." This being true, the transient currents consist of one or more terms of the general form:

$$i = I\,\epsilon^{-\alpha t} \sin(\omega\, t + \theta)$$

The way in which this current varies depends upon the values of α and ω. There are four types of variations, only two of which occur as transients. If α and ω are both zero, it is a steady direct current of value, $I \sin \theta$. If α is a positive quantity, as it always is, and ω is zero, it is a diminishing direct current of value, $I\,\epsilon^{-\alpha t} \sin \theta$. If α is zero and ω is a positive quantity, it is a steady sinusoidal current of value, $I \sin (\omega\, t + \theta)$. And finally, if neither α nor ω are zero, it is a diminishing sinusoidal current. In each of these cases the current, whether steady or transient, may be represented by a vector which in general has a length of $I\,\epsilon^{-\alpha t}$ and which makes an angle of $(\omega\, t + \theta)$ with the horizontal axis. The projection of this vector on the vertical axis is the instantaneous value of the current. The four cases are illustrated in Fig. 1, *a*, *b*, *c* and *d*.

In each of the diagrams I marks the initial position of the vector. In the first case (*a*) the vector is fixed both in magnitude and in angular position. In the second case (*b*) the magnitude of the vector diminishes exponentially although its angular position does not change. In the third case (*c*) the vector has a constant

1. See Bibliography.

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magnitude but rotates with an angular velocity of ω. In the fourth and general case (d) the magnitude of the vector diminishes exponentially while it rotates at a constant angular velocity of ω. Thus the general form of transient current may be represented by a vector which rotates at a constant angular velocity and whose terminus travels along a logarithmic spiral.

The velocity of the terminus of the vector has two components, one along the vector and one perpendicular to it. It is convenient to measure these component velocities in multiples of the instantaneous length of the vector. The term angular velocity is thus appropriate. This is a broader meaning of angular velocity than is ordinarily assigned to it, and for this reason, it is spoken of as the generalized angular velocity. Differentiation shows that the generalized angular velocity of this vector is, $m = (-\alpha + j\,\omega)$. See Fig. 2. Notice that the usual significance is attached to the symbol j. It indicates that the vector $j\,\omega$, lags the vector, $-\alpha$, by 90 degrees.

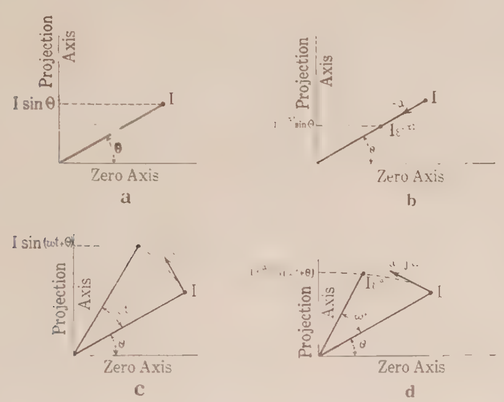

Fig. 1—The End of Each Vector Which is Drawn From the Origin is Indicated by a Large Period; the End of Small Vectors Drawn from These Periods is Indicated by Arrowheads.

The form of the current variation is determined by the generalized angular velocity; the magnitude is determined by the coefficient I, and the phase, by the angle, θ.

It is interesting to note that the current is passing through a maximum value at the moment that the current vector makes an angle arc tan α/ω with the projection axis. This occurs when the vector is in such a position that the angular velocity m, drawn from its terminus, is perpendicular to the projection axis. See Fig. 3. A steady sinusoidal current is maximum at the moment that the vector representing it lies in the projection axis.

The behavior of damped sinusoidal currents in electric circuits, having resistance inductance and capacitance, has been the subject of considerable investigation, and is familiar, especially to those who have been interested in radio communication. The field of application of this theory, however, is much broader than this, and may easily be extended to include practically all electric machinery, both alternating and direct-current.

Currents and pressures that have the same generalized angular velocity can, of course, be combined by the customary principles of vector addition. The resulting vector diagrams will then be similar to those which apply to the steady state, save that the electromotive forces due to induction, both self and mutual, are not in time quadrature with the current, as we shall presently see. It is further understood that, as they rotate, all of the vectors shrink exponentially.

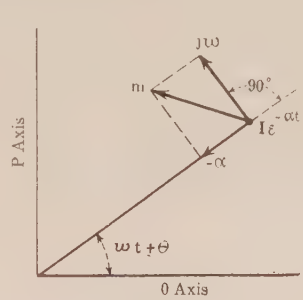

Fig. 2

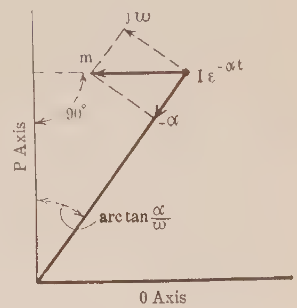

Fig. 3

Inasmuch as those who are interested in the operation of electric machinery have had little contact with the theory of damped sinusoidal currents, it may be well to show how these currents and the electric pressures they produce can be represented by vectors. In all of the following analyses any capacitance that the circuit may possess will be disregarded. This, of course, places a definite limitation upon the scope of the analysis and prevents the discussion of certain transient conditions, particularly those of relatively high frequency, which are very important in transmission circuits.

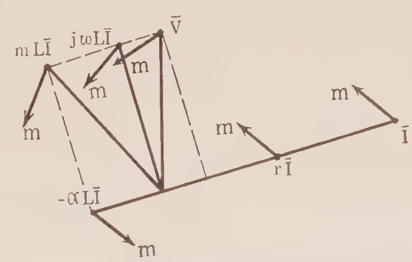

Fig. 4

When a current of the general form flows through a non-reactive resistance the *fall* in potential is $r\,I\,\epsilon^{-\alpha t}$ $\sin\,(\omega\,t + \theta)$. This may be represented vectorially as in Fig. 4. The *fall* in potential through an inductance is:

$$L\,\frac{d\,i}{d\,t} = -\,\alpha\,L\,I\,\epsilon^{-\alpha t}\sin\,(\omega\,t + \theta) + \omega\,L\,I\,\epsilon^{-\alpha t}\cos\,(\omega\,t + \theta)$$

The first of these components may be represented by a vector in opposition to the current vector, and the second by a vector which leads the current by 90 degrees.

See Fig. 4. In this figure and hereafter a line drawn above a letter indicates that it represents a current or pressure of the general form.

Thus: $\bar{V} = r\,\bar{I} + (-\,\alpha + j\,\omega)\,L\,\bar{I}$

or $\bar{V} = (r + m\,L)\,\bar{I}$

where m represents the generalized angular velocity of the current vector; the generalized impedance is $(r + m\,L)$.

In Fig. 4 notice that there is a *rise* in potential through the circuit, numerically equal to $\alpha\,L\,I$, which is in time phase with the current. This indicates that electric energy is being generated within the circuit, due to the diminution of the magnetic field. The power so generated, $\alpha\,L\,I^2$, partially supplies the copper loss, $I^2\,r$, in the circuit. The vector representing the fall in pressure due to self inductance leads the vector representing the current by arc tan α/ω more than 90 deg. It is in this respect that the vector diagrams representing the transient state differ from those that represent the steady state.

If the electric circuit is linked with a magnetic circuit in which eddy current and hysteresis losses may occur, it is customary, though strictly speaking it is incorrect, to represent both the current and the magnetic flux by vectors when they have a steady sinusoidal variation.

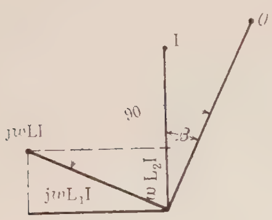

FIG. 5

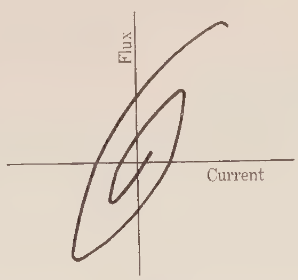

FIG. 6

In this case the flux is represented as lagging the current which produces it by a constant angle β. See Fig. 5. This is equivalent to assuming that the hysteresis loop is an ellipse and that the eddy currents are all in time quadrature with the flux in the core. The fall in reactive pressure $j\,\omega\,L\,I$, leads the flux, ϕ, by 90 deg., but the current by an angle which is somewhat less. This being the case, it is necessary to represent the inductance by a complex number, i. e. $L = L_1 - j\,L_2$; where $L_2/L_1 = \tan\beta$. Thus $j\,\omega\,L\,I = j\,\omega\,(L_1 - j\,L_2)\,I = \omega\,L_2\,I + j\,\omega\,L_1\,I$

Similarly if the current is of the general form,—and we make the same assumption in regard to the constancy of the phase angle between the flux and the current,—the fall in pressure due to inductance is $(-\,\alpha + j\,\omega)\,(L_1 - j\,L_2)\,\bar{I}$, which may still be written $m\,L\,\bar{I}$, understanding now that both m and L are complex numbers. On expansion, this becomes $[\,(-\,\alpha\,L_1 + \omega\,L_2) + j\,(\omega\,L_1 + \alpha\,L_2)\,]\,\bar{I}$. If $\alpha\,L_1$ equals $\omega\,L_2$, i. e. if $\alpha/\omega = \tan\beta$, the fall in pressure due to inductance is in exact quadrature with the current and the energy given up by the magnetic field due to its collapse is just sufficient to supply the core losses. The power absorbed in the coil is then equal to the copper loss. If, with the same frequency, the rate of collapse of the magnetic field is greater than this, the coil absorbs less power than the copper loss.

If there is another electric circuit linking the same magnetic core, the fall in electric pressure through it produced by the action of the current in the first circuit is $j\,\omega\,M\,\bar{I}_1$. Notice that this is a vector which leads the current vector by more than 90 deg. When there are core losses in the mutual magnetic circuit the mutual inductance, M_1, might likewise be represented by a complex number of the form, $M_1 - j\,M_2$.

Only considerable research can determine the value of this suggestion that the self and mutual inductance be represented by complex numbers when the currents are decaying sinusoids. It should be noted that there is a constant lag angle of flux with respect to magnetizing current only if the hysteresis "loop" is a diminishing ellipse such as shown in Fig. 6. This is, of course, not true and whether it is justifiable can only be determined by experiment.

In any inductive circuit the current cannot immediately respond to an abrupt change in the magnitude or form of the applied electromotive forces. There is always a transient condition of current flow, the duration of which is determined by the inductance and resistance of the circuit. Moreover, the form of this transient flow is determined solely by these constants and is wholly independent of the character of the applied electromotive forces. The magnitude and phase of the transient, however, are determined by the initial and final values of the current in the circuit, and these are fixed by the applied electromotive forces.

Two Circuits Having Mutual Inductance but No Motion with Respect to Each Other

The simplest case we shall consider is that of a single-phase transformer which is simultaneously short-circuited on both primary and secondary sides.

With the primary winding short-circuited the fall in pressure through it is zero.

$$\bar{I}_1\,r_1 + \bar{I}_1\,m\,L_1 + \bar{I}_2\,m\,M = O \qquad (1)$$

r_1 and L_1 represent the resistance and self inductance, not leakage inductance, of the primary. M is the mutual inductance between primary and secondary. Likewise:

$$\bar{I}_2\,r_2 + \bar{I}_2\,m\,L_2 + \bar{I}_1\,m\,M = O \qquad (2)$$

The primary and secondary currents have the same form and thus the same generalized angular velocity. Eliminating $\bar{I}_1$ and $\bar{I}_2$ from equations (1) and (2) gives:

$$(r_1 + m\,L_1)\,(r_2 + m\,L_2) = m^2\,M^2$$

Expand and divide each term by $L_1\,L_2$ giving,

$$\sigma\,m^2 + (k_1 + k_2)\,m + k_1\,k_2 = O \qquad (3)$$

where $\sigma = 1 - \dfrac{M^2}{L_1\,L_2}$ $\quad k_1 = r_1/L_1$ and $k_2 = r_2/L_2$

By some writers σ is called the leakage coefficient, whereas others define the leakage coefficient as $\frac{L_1 L_2}{M^2} - 1$. In the latter case $\left(\frac{L_1 L_2}{M^2} - 1\right) = \sigma' = \frac{\sigma}{1 - \sigma}$; or $\sigma = \frac{\sigma'}{1 + \sigma'}$. In a transformer in which the resistance of the windings may be neglected this leakage coefficient, σ, is the ratio of the current on open circuit to that on short circuit with the same applied potential. k_1 and k_2 are the reciprocals of the time constants of the two windings on open circuit.

The solution for the generalized angular velocity is

$$m = - \frac{k_1 + k_2}{2\,\sigma} \pm \frac{\sqrt{(k_1 + k_2)^2 - 4\,\sigma\, k_1\, k_2}}{2\,\sigma} \tag{4}$$

Since σ is less than unity, the values of m are both real, and the transient current consists of two direct-current components one of which diminishes much faster than the other. These currents may be represented by vectors as in Fig. 1B.

In this case, in which both windings are short-circuited, there will be no current in either winding after the transient has disappeared. Thus the only current after short-circuit occurs is the transient. Let the vectors I_{10} and I_{20} represent the primary and secondary currents before short circuit occurs. Also let $\bar{I}_1'$ and $\bar{I}_1''$ represent the components of the transient current in the primary and similarly for the secondary. Then at the moment of short circuit, the sum of the instantaneous values of the two transient components must equal the instantaneous value of the initial current in both primary and secondary. The transient components might thus be represented by an indefinitely great number of vectors since it is only necessary that their projection on the given axis have specified values. It is more convenient, however, if they are chosen so that their vector sum is equal to the vector representing the initial current before short circuit. Thus we will write:

$$I_{10} = \bar{I}_1' + \bar{I}_1'' \tag{5}$$

and

$$I_{20} = \bar{I}_2' + \bar{I}_2'' \tag{6}$$

Remember that the vectors $\bar{I}_1'$, etc., are diminishing exponentially and that this equality holds only at the moment of short circuit. Further, notice that the vectors I_{10} and I_{20} are drawn to represent the *maximum* values of the currents before short circuit. Each of these transient components must satisfy equations (1) and (2). Substitute in equation (1) and write in the following form:

$$\bar{I}_1' \frac{(r_1 + m'\,L_1)}{m'\,M} = - \bar{I}_2'$$

also

$$\bar{I}_1'' \frac{(r_1 + m''\,L_1)}{m''\,M} = - \bar{I}_2''$$

where m' and m'' are the two values of m as indicated by equation (4). If these equations are added and $(I_{10} - \bar{I}_1')$ is substituted for $\bar{I}_1''$ the solution for $\bar{I}_1'$ is:

$$I_1' = \frac{m'\,m''}{k_1\,(m' - m'')} \{ (k_1/m'' + 1)\, I_{10} + \sqrt{1 - \sigma}\, \sqrt{L_2/L_1}\, I_{20} \} \tag{7}$$

also

$$I_1'' = \frac{m'\,m''}{k_1\,(m'' - m')} \{ (k_1/m' + 1)\, I_{10} + \sqrt{1 - \sigma}\, \sqrt{L_2/L_1}\, I_{20} \} \tag{8}$$

The product of the two roots divided by their difference is

$$\frac{m'\,m''}{m' - m''} = \frac{k_1\, k_2}{\sqrt{(k_1 + k_2)^2 - 4\,\sigma\, k_1\, k_2}}$$

In a transformer the ratio of the self-inductances of the primary and secondary is practically equal to the square of the ratio of the turns. Thus as is commonly said, $\sqrt{L_2/L_1}\, I_{20}$ is the secondary current referred to the primary. In order to reduce these expressions to a more understandable form, we will assume that k_1 equals k_2. This is very nearly true. If this is done the two components of the primary current become:

$$\bar{I}_1' = 1/2\,(I_{10} + I_{20}) \tag{9}$$

$$\bar{I}_1'' = 1/2\,(I_{10} - I_{20}) \tag{10}$$

where I_{20} is now the secondary current referred to the primary. The values of m reduce to:

$$m' = - \frac{r}{L + M}$$

$$m'' = - \frac{r}{L - M}$$

where r and L are the resistance and self-inductance of the primary winding, and M is the mutual inductance on the assumption that both windings have the same number of turns. In this case the difference of the self and mutual inductances is the leakage inductance of one winding. The two components of the transient secondary current are similar to those of the primary. Thus at the moment of short circuit each of the currents in the two windings breaks up into two components, one of which is one-half of the no-load current; $(I_{10} + I_{20})$ is the no-load current. This component decays at a rate determined by the resistance and the sum of the self and mutual inductances of the two windings. It is due to the energy stored in the magnetic core of the transformer. Its rate of decay is much slower than that of the other component. The latter's rate of decay is determined by the resistance and leakage inductance of the windings, and this component of the currents is due to the energy stored in the leakage field. The vector diagram and oscillograph record are given in Fig. 7. In this figure the vectors I_1 and I_2, representing the primary and secondary currents,

are rotating at an angular velocity of ω. At the moment of short circuit each of these vectors abruptly stops and breaks up into two component vectors which diminish at different rates.

The more usual transient condition would be one in which the short circuit occurred on the secondary side alone. In this case the current immediately after short circuit consists of the transient current together with the steady value of the short-circuit current. The conditions that must be satisfied are now:

$$I_{10} = \bar{I}_1' + \bar{I}_1'' + I_{sc1} \qquad (11)$$

and

$$I_{20} = \bar{I}_2' + \bar{I}_2'' + I_{sc2} \qquad (12)$$

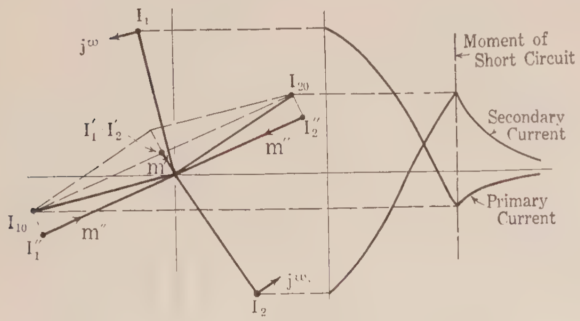

Fig. 7

where I_{sc1} and I_{sc2} represent the steady values of the short-circuit currents in the primary and secondary windings. As before this is a vector equation which holds only at the moment of short circuit. If these steady short-circuit currents are transferred to the left of the equality sign it is readily seen that the values of the components of the transient currents become:

$$I_1' = 1/2\,(I_{10} + I_{20}) - 1/2\,(I_{sc1} + I_{sc2}) \qquad (13)$$

$$I_1'' = 1/2\,(I_{10} - I_{20}) - 1/2\,(I_{sc1} - I_{sc2}) \qquad (14)$$

As before the secondary components are similar to the primary components. It is now necessary to determine the phase relation between the steady short-circuit current and the current in the transformer before the short circuit occurs.

In order to keep the diagrams as simple as possible, we will make the customary assumption that the primary and secondary currents are equal and in phase opposition. In that case the first component of the transient current is zero, and the second component is equal to the current before short circuit minus the steady short-circuit current. [See equations (13) and (14)] with $I_{10} = - I_{20}$ and $I_{sc1} = - I_{sc2}$. The error thus introduced is usually very slight. The vector diagram at the moment of short circuit is given in Fig. 8.

Before short circuit occurs only the four vectors representing the primary and secondary potentials and current appear. They are rotating at a uniform angular velocity, ω. At the instant after short circuit all of these except the primary potential disappear and in their place spring the steady short-circuit currents. I_{sc1} and I_{sc2} and the transient currents I_1'' and I_2''. The former continue to rotate at an angular velocity of ω without change in magnitude, while the latter remain fixed in angular position but diminish exponentially at a rate, α, depending upon the resistance and leakage inductance of the windings. The arrows at the ends of the vectors indicate the direction of their motion. Observe that, at the moment of short circuit, the current before short circuit is the vector sum of the steady short-circuit current and the transient current. Since the steady short-circuit current is from 10 to 25 times the full-load current, it makes little difference whether the short circuit comes at a time of full load or no load. It may be a little more severe at no load. On account of the excessive value of the steady short-circuit current, the vectors representing *it* and the *transient current* are essentially in phase opposition at the moment of short circuit. Half a cycle after short circuit occurs the vector I_{sc1} will thus have overtaken the stationary vector I_1'' and their vector sum will be a maximum. It at once follows that short circuit is most severe when it occurs at a moment that the steady short-circuit current would be a maximum.[2] Since the steady short-circuit current and applied potential are nearly in quadrature, for example, the power factor of a certain 1000-kv-a., 60-cycle transformer is 0.15 at short circuit,—the worst moment for a short circuit to occur is at about the time

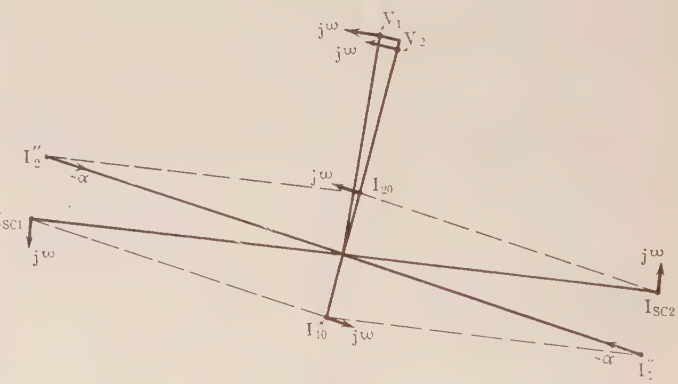

Fig. 8

that the applied potential is passing through zero. In the transformer just cited the ratio of the resistance to the leakage inductance is 56 and thus in the time of one half cycle the transient current will have fallen to $\epsilon^{-\frac{56}{120}}$ or 63 per cent of its initial value. Thus the first current rush would be to a value which is 63 per cent greater than the maximum value of the steady short-circuit current which is itself more than 20 times the maximum value of the full-load current. The

2. To determine the exact moment at which the short-circuit current would be a maximum involves the solution of a mixed trigonometric and exponential equation, which is decidedly not worth while in the present problem.

forces between turns vary as the square of the current, and thus the first shock on this transformer may be 265 per cent of its ultimate maximum value.

When these forces have their maximum value they occur one-one-hundred-and-twentieth (1/120) of a second after short circuit in a sixty-cycle transformer and one-fiftieth (1/50) of a second after short-circuit in a twenty-five-cycle transformer. Nevertheless with transformers having the same short-circuit characteristics (volts, amperes, and watts on short-circuit test), the maximum forces that the windings must sustain are the same for all frequencies.

If the transformer is but a portion of the electric circuit in which the transient takes place the characteristic equations (**1**) and (**2**) must be written:

$$\bar{I}_1 r_1 + \bar{I}_1 m L_1 + \bar{I}_2 m M = \bar{V}_1 \qquad (\mathbf{15})$$

$$\bar{I}_2 r_2 + \bar{I}_2 m L_2 + \bar{I}_1 m M = \bar{V}_2 \qquad (\mathbf{16})$$

$\bar{V}_1$ and $\bar{V}_2$ are the transient potentials which appear at the terminals of the transformer. If the transformer has a relatively small exciting current little error will be made if it is treated like a simple inductive reactance. In this case the relation between the primary and secondary pressures is much simpler.

$$\bar{V}_1 - \bar{I}_1 (R + m L) = a \bar{V}_2 \qquad (\mathbf{17})$$

R and L are the equivalent resistance and leakage inductance of the two windings and a is the ratio of transformation at no load.

Two Circuits Having Mutual Inductance, in One of Which There is a Commutated Rotational E. M. F.

Before turning our attention to polyphase rotating machines, it might be well to consider briefly the direct-current dynamo of either the shunt or compound type. This apparatus is in some respects quite similar to the transformer. It has two circuits which are mutually inductive, the armature and series field forming one and the shunt field the other. There is this difference, however: an electromotive force is generated in the armature circuit by its rotation in a magnetic field that is due to the joint action of the current in both circuits. With constant speed this generated e. m. f., is proportional to the magnetic field. The relation between the magnetic field and the currents in the armature and shunt field circuits which produce it is similar to the well-known hysteresis loop, for which there is no simple mathematical expression. In some problems in which the exciting current is a steady alternating one, it has been found convenient, however, to assume that this hysteresis loop is an ellipse. If this assumption should prove sufficiently accurate in the present case also, it will simplify the problem greatly, for as has been already suggested, we may then represent the magnetic field and the rotational e. m. f. which it produces, together with the net exciting ampere-turns by vectors even when these quantities are damped sinusoids, *i. e.*, of the general form. This vector relation is shown in Fig. 9, which is drawn for the steady state.

The flux, ϕ, and the rotational e. m. f. E which is proportional to it, lag the exciting current I by a constant angle β. Thus we may write

$$E = (K_2 - j K_2)\, I \qquad (\mathbf{18})$$

$$\text{or } E = K\, I$$

where K is a complex number, $K_1 - j K_2$, having the dimensions of resistance. The vector equation shows that when the instantaneous value of the current is zero

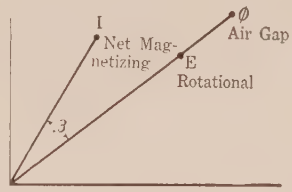

Fig. 9

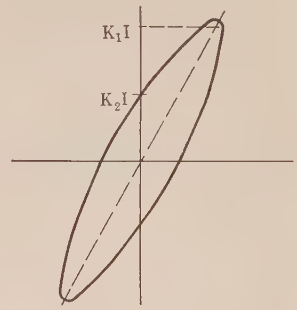

Fig. 10

the generated e. m. f. is $K_2 I$. This is generally referred to as the residual voltage. At the moment that the current has its greatest value the rotational e. m. f. is $K_1 I$. If the exciting current is going through a steady cyclic variation, it is a simple matter to determine these two components of the e. m. f. See Fig. 10. When the current is a damped sinusoid, however, the vector representing it is shorter at the moment that it is perpendicular to the time axis than it was earlier in the cycle when the current was passing through

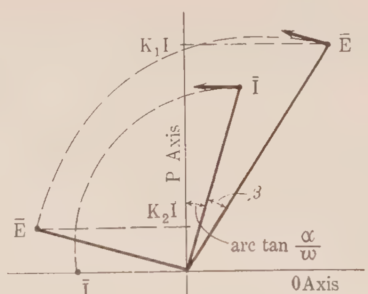

Fig. 11

its maximum value. See Fig. 11. In this case the best method of determining the constants K_1 and K_2, in order to assure the greatest accuracy in the calculations can only be determined by experiment.

Let $\bar{I}_1$ and $\bar{I}_2$ be the currents in the armature and shunt field circuits and similarly, r_1 and L_1, the resistance and self-induction of the one, and r_2 and L_2, the same constants of the other. Also let M be the mutual inductance between the two circuits. The e. m. f., $\bar{E}$, generated in the armature circuit by rotation is:

$$\bar{E} = K\,(N_1/N_2\, \bar{I}_1 + \bar{I}_2);$$

where N_1 and N_2 are the effective turns in each circuit

acting on the main magnetic axis. Let $N_1/N_2 = a$. Also let $\overline{V}$ be the rise in terminal pressure across both the armature and shunt field circuits.

Then we have:

$$\overline{V} = \bar{E} - \bar{I}_1 r_1 - \bar{I}_1 m L_1 - \bar{I}_2 m M \quad \text{(armature circuit)}$$

$$= \bar{I}_1 (K a - r_1 - m L_1) + \bar{I}_2 (K - m M) \quad (19)$$

also $$\overline{V} = - \bar{I}_2 r_2 - \bar{I}_2 m L_2 - \bar{I}_1 m M \quad \text{(shunt field circuit)}$$

$$= - \bar{I}_2 (r_2 + m L_2) - \bar{I}_1 m M \quad (20)$$

If these equations, (19) and (20), are solved for $\bar{I}_1$ and $\bar{I}_2$ we have:

$$\bar{I}_1 = \frac{r_2 + m L_2 + K - m M}{(K a - r_1 - m L_1)(r_2 + m L_2) - (K - m M) m M} \overline{V}$$

and $$\bar{I}_2 = - \frac{K a - r_1 - m L_1 + m M}{(K a - r_1 - m L_1)(r_2 + m L_2) - (K - m M) m M} \overline{V}$$

The total net current delivered, $\bar{I} = \bar{I}_1 + \bar{I}_2$, is

$$\bar{I} = \frac{r_1 + r_2 + K(1 - a) + m(L_1 + L_2 - 2M)}{(K a - r_1 - m L_1)(r_2 + m L_2) - (K - m M) m M} \overline{V}$$

The ratio of the fall in terminal potential, $-\overline{V}$, to the total current is the generalized impedance, Z, of the dynamo. Thus we have:

$$Z = \frac{(K - m M) m M - (K a - r_1 - m L_1)(r_2 + m L_2)}{r_1 + r_2 + K(1 - a) + m(L_1 + L_2 - 2M)}$$

For further discussion of this problem the reader is referred to the paper by Doherty on "Exciter Instability" presented at the Pacific Coast Convention, August, 1922.

Two Systems of Balanced Polyphase Circuits Having a Constant Relative Angular Velocity

The author believes that the simplest method of presenting the analysis of the transient condition in polyphase induction and synchronous machines is that which considers the rotating magnetic fields in the air gap and the reactions which they produce. When these polyphase machines are operating under balanced conditions, either steady or transient, the currents in the several phases of the polyphase winding may be represented by vectors of equal length equally spaced with respect to each other. For the steady condition the vectors are of constant length and rotate at a constant angular velocity. This representation has been used for many years. The *only* difference between the steady and the transient condition is that the vectors which represent the latter state diminish exponentially as they rotate. If this conception of the transient state is borne in mind the following analysis is readily followed by anyone who is familiar with the steady operation of these machines. In all that follows the relative speed of the two windings is assumed to remain constant throughout the time considered. Since the maximum current occurs within about a half-cycle after the transient begins the angular velocity of the moving part has little opportunity to change before the first shock is over.

The parallel lines in Fig. 12 represent the uniform air gap of a three-phase induction motor. The phase belts of the stator conductors are indicated at the letters a, b, c. The pole pitch is from $+a$ to $-a$. If this winding is properly designed, there will be very small harmonics in the space distribution of the air-gap flux density when the alternating currents are balanced. We will neglect whatever harmonics may exist and assume that this distribution may be represented by a sinusoidal curve such as β. The line $X - X$ is the axis of this curve. If the current in phase b lags that in phase a by 120 deg. this magnetic field will move toward the right at a constant angular velocity of ω radians per second; where ω equals the frequency of the alternating current multiplied by 2π. On the other hand, if the current in phase b leads that in phase

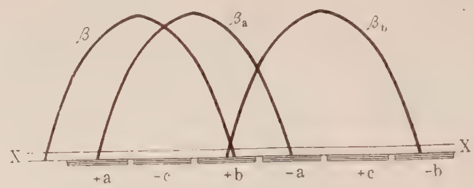

Fig. 12

a the field moves toward the left at the same velocity. In all that follows we shall consider that a velocity toward the right is positive and that one toward the left is negative. Furthermore, the magnitude of the field as well as its form, will not change as it moves, and thus the field might be represented by a rotating vector whose projection on a fixed axis indicates the amount of flux linking any particular phase. The angular displacement of this vector from the fixed axis is always the angle between the axis of the moving field and the axis of the phase considered. See Fig. 13. One of the most important points in the theory of rotating fields that are produced in this manner in a uniform air gap is that the flux through any phase is a maximum at the moment that the current in that phase is also a maximum. For example, when the current in phase a is maximum the field is in the position β_a. One sixth of a cycle later, the current in $-c$ will be a maximum and in the same time interval, the flux distribution will have moved one sixth of two full pole pitches toward the right and be a maximum through this phase, $-c$. In a similar manner, it will have moved into the position β_b by the time that the current in phase b is a maximum. This can be represented vectorially as in Fig. 13. The current and flux are

represented by the rotating vectors I and φ. The instantaneous value of the current in any phase or the flux through that phase is the projection of the corresponding vector on the axis of that phase. In Fig. 13 the vectors are drawn for the time that the current in phase $-c$ has its maximum value. Notice that for both the phases a and b the currents in them and the fluxes through them are each one half of their maximum values. There is this difference, however, for while the values are decreasing for phase a they are increasing for phase b, in which they will be a maximum 1/6 of a cycle later. Ordinarily, we are content to know the current and flux in any one phase, a, for example, and then the projection axes for the other phases are not drawn.

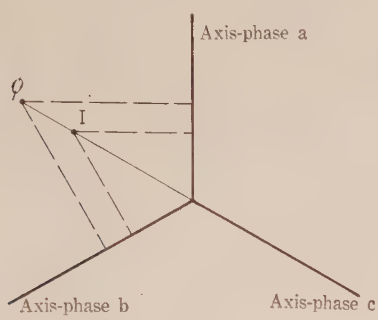

FIG. 13

It may be convenient and possibly necessary in some problems to consider magnetic fields that rotate to the left, that is, with a negative angular velocity. In this case the vector, φ, representing the flux through any phase would likewise have a negative angular velocity and would thus move in the clockwise direction. If the trigonometric expressions for the instantaneous currents in the phases are written it will be noticed that giving a negative value to ω is equivalent to reversing the phase order of the currents. Such a reversal of phase order reverses the direction of rotation of the magnetic field produced by the current. If the current vector in Fig. 13 is rotated in the negative or clockwise direction it will be noticed that the current in phase b will lead that in phase a by one-third of a cycle, that is the phase order of the currents is reversed. We must be most careful, however, to remember that, if it is necessary to combine or operate on these vectors, whether they have positive or negative angular velocities the operator j *always* indicates a phase rotation of one quadrant in the positive or counter clockwise direction. If this is not done we may become hopelessly confused. If the air gap is not uniform, as is the case with salient pole machines, the curve of flux density will alter both its shape and magnitude as it rotates, but that is a complication which it is well for the present to disregard, leaving its consideration until some future time.

In general if the currents in the several phases of a symmetrical n-phase winding have values equal to the projections of a "current" vector on each of a system of n equally spaced axes, the magnetic flux linking any winding is equal to the projection of a "flux" vector, which is drawn in phase with the "current" vector, on the axis corresponding to that winding. This assumes that the windings are so designed that there are essentially no harmonics in the space distribution of the magnetic field and that each winding will, if acting alone, produce exactly the same flux per ampere.

If the currents are of the general form both the "current" and "flux" vectors shrink exponentially as they rotate. The space distribution of the magnetic field is still sinusoidal at all times but its magnitude diminishes as it moves through the air gap. Compare Fig. 13 with Fig. 14. In the latter figure let us assume that the currents took on the general form at the moment that the flux distribution was at the point indicated by the curve β, and that their generalized angular velocity is $(-\alpha + j\,\omega)$. The equation of the maximum density for any later position of the field such as β_1 is: $B_m = B_o \epsilon^{-\alpha t}$; where t is the time required for the field to move from the position β to β_1, *i. e.*, through an angular distance X.

The flux through any phase as well as the current in it may still be represented by a vector although this vector is now of the general type—that is, it shrinks exponentially as it rotates. A current or flux variation of the general form reaches its maximum value in any phase at the moment that the vector which represents it is still arc tan α/ω from the projection axis of this phase. Because the field is shrinking as it rotates the flux linking phase a is greater when the field is in the position β_1 than when it is in the position β_2 at which moment the axis of the field is coincident

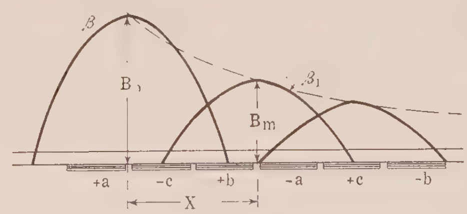

FIG. 14

with the axis of the phase. See Fig. 15. Thus the flux through any phase is a maximum at the moment that the current in the phase is a maximum, but the flux distribution is no longer directly opposite the phase when this occurs, as was the case when the currents were steady sinusoids.

It is then evident that even in the transient state the flux through any phase and the current in that phase may still be represented by coincident vectors.

The electromotive force generated by this rotating field is the negative of the time rate of change of the flux linkages. Thus, in general, when this time rate of flux change in any phase is zero the e. m. f. is zero and the flux linking the phase is a maximum. In Fig.

16 the flux in phase a is a maximum when the vector representing it is in the position shown. At this moment the e. m. f. is zero and the vector, $\bar{E}$, representing it must, therefore, be perpendicular to the projection axis. An additional proof of this is interesting even if unnecessary. Consider Fig. 15. When the field is in the position β_1 the e. m. f. produced in the phase a has two components, one due to the motion of the field and the other due to its shrinking. The motional e. m. f. is proportional to the velocity of the field and to the sine of the angle, ωt, between the field and the phase winding. If at the point $+a$, the

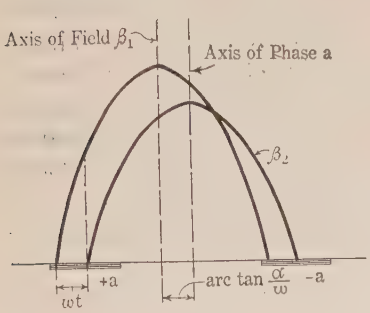

FIG. 15

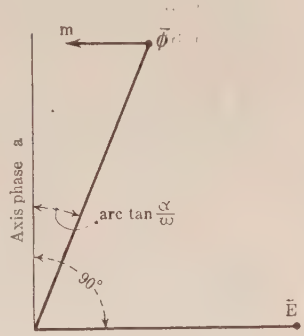

FIG. 16

direction of the flux density is upward and the motion of the field is to the right the e. m. f. generated in the belt, $+a$, is away from the observer. On the other hand if the field within a circuit changes an e. m. f. is set up which is proportional to the rate of change and is in such a direction as to oppose the change. The e. m. f. thus produced is proportional to $\alpha \cos \omega t$, and is toward the observer in the belt of conductors $+a$. If the angular displacement, ωt, is so chosen that the resulting e. m. f. is zero, $\omega \sin \omega t$ equals $\alpha \cos \omega t$. That is to say, the angular displacement of the flux distribution is arc tan α/ω. Observe that the fall in potential, $-\bar{E}$, leads the flux, $\bar{\phi}$, by an angle, $\pi/2$ + arc tan α/ω, just as does the fall in potential due to self induction. Thus, in a polyphase winding we may combine the fall in pressure due to the so-called leakage flux in one phase with the fall in pressure in this phase due to the mutual air-gap flux which is produced by all phases. This is commonly done in the analysis of synchronous machines and the resulting loss in pressure is the so-called synchronous inductance, or reactance drop. If L represents the synchronous inductance, a transient current, $\bar{I}$, having a generalized angular velocity m, will produce a fall in potential of $m L\bar{I}$. This fall in potential is represented by a vector which is $\pi/2$ + arc tan α/ω ahead of the current vector.

This conception of the action of a rotating field of the transient type may be summarized as follows: Consider two groups of symmetrical polyphase windings, a and b, the first of which is stationary and the second, moving in the positive direction at an angular velocity of p radians per sec. The projection axis for the stationary winding is stationary, while the projection axis for the moving winding is moving at the same angular velocity, *viz.* p, as indicated in Fig. 17. If the angular velocity of the currents in the stationary, or a, winding, is ω radians per sec., the relative angular velocity of the magnetic field due to these currents with respect to the b winding is $(\omega - p)$ radians per sec. in the positive direction. The flux linking any phase of the b winding is a maximum arc tan

$$\frac{\alpha}{\omega - p}$$

before the flux vector lies in the projection axis of this phase. If the field is moving with respect to the b winding in the positive direction the flux will be a maximum when the flux vector is at $\bar{\phi}_a'$. See Fig. 17. If the field is moving relatively in the negative direction, *i. e.* if p is greater than ω, the flux will be a maximum when the flux vector is at $\bar{\phi}_a''$. At the moment that the flux is a maximum through any phase, the generated e. m. f. in this phase is zero and the vector representing it will be at E_b' for a positive relative angular velocity and at E_b'' for a negative velocity. This generated e. m. f. is equal to the product of the current in one phase of the a windings, the relative generalized angular velocity with respect to the b windings of the field that these currents produce, and the mutual inductance between the a and b windings. The mutual inductance M can be measured as follows: Fix the a and b windings with respect to each

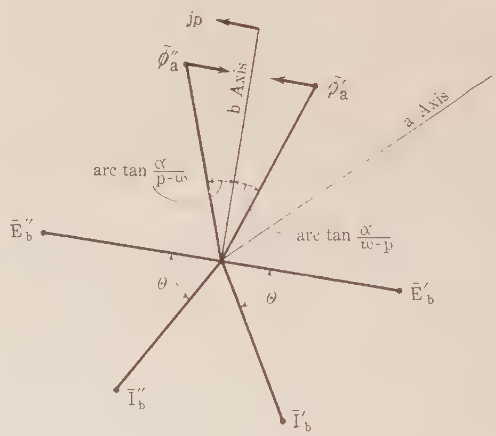

FIG. 17

other and send balanced polyphase currents through either, the a for windings for example. The mutual inductance M is the e. m. f. generated in one phase of the other, or b winding, divided by the product of the current in one phase of the a winding and angular velocity of this current. By the time that the flux has advanced $\pi/2$ – arc tan $\dfrac{\alpha}{\omega - p}$ with respect to the b windings, the generated e. m. f. will have reached its maximum value, but the current will usually not reach its maximum value until somewhat later depending

upon the constants of the b windings and their terminal pressure. In any case, however, the current will be represented by a vector equal to $\frac{\bar{E}_b - \bar{V}_b}{r_b + m\,L_b}$; where $\bar{V}_b$ is the terminal pressure, r_b the resistance and L_b the synchronous inductance of one of the b phases. By the time the current in the winding has reached its maximum value the field will have advanced a further relative angle of θ. Thus whether the motion of the a field is positive or negative, its action on the b winding will develop a field which will always lag the a field in its motion with respect to the b winding. Consider an induction machine in which the magnetic field due to the stator, a windings, rotates in the positive direction at ω radians per sec. If the rotor turns in the same direction at less than this synchronous speed the relative motion of the stator field with respect to the rotor is positive. The rotor component of magnetic field actually and apparently lags the stator field. If the rotor turns in the same direction at a speed greater than synchronous, the relative motion of the stator field with respect to the rotor is negative and the rotor component of field apparently leads when observed from the fixed stator, though it actually lags, as would be observed from any point on the rotor itself. It is interesting that these well-known facts should apply to the transient state as well as to the steady operating condition.

Having established these general principles in regard to rotating fields during the transient state the solution for the transient currents in an induction motor may be written down without further explanation. If the generalized angular velocity of the stator currents is m the relative generalized angular velocity of the field produced by these currents with respect to the rotor is $(m - j\,p)$. Since $m = -\alpha + j\,\omega$ and the relative angular velocity of the stator magnetic field and the rotor winding is $(\omega - p)$, the generalized angular velocity of the rotor currents is $-\alpha + j\,(\omega - p)$, *i. e.*, $m - j\,p$. The generalized angular velocity of the rotor currents is thus $m - j\,p$, but the relative angular velocity with respect to the stator of the field produced by them is $[m - j\,p - (-j\,p)]$, *i. e.*, m. The second $(-j\,p)$ is the relative angular velocity of the stator with respect to the rotor. Thus we have:

$$\bar{E}_2 = -(m - j\,p)\,M\,\bar{I}_1 \qquad (19)$$

$$\bar{E}_1 = -m\,M\,\bar{I}_2 \qquad (20)$$

$\bar{E}_2$ and $\bar{E}_1$ are respectively the generated e. m. f. due to the stator currents in the rotor and that due to the rotor currents in the stator. The rotor current, $\bar{I}_2$, is:

$$\bar{I}_2 = \bar{E}_2/Z_2 \qquad (21)$$

where Z_2 is the generalized self impedance of the rotor calculated for a generalized angular velocity of $m - j\,p$. The stator current $\bar{I}_1$, is:

$$\bar{I}_1 = \frac{\bar{E}_1 - \bar{V}_1}{Z_1} \qquad (22)$$

where Z_1 is similarly the generalized self impedance of the stator calculated for a generalized angular velocity of m, and $\bar{V}_1$ is the transient terminal pressure of the stator. Combining these four simple relations gives the characteristic equation for the stator current of an inductor motor during the transient period. That is:

$$\bar{I}_1 = -\frac{Z_2}{Z_1\,Z_2 - m\,(m - j\,p)\,M^2}\,\bar{V}_1 \qquad (23)$$

$$= \frac{-\bar{V}_1}{Z_T}$$

where $-V_1$ is the fall in terminal pressure across one phase of the stator. That is, it may be said that the transient impedance of an induction machine is:

$$Z_T = \frac{Z_1\,Z_2 - m\,(m - j\,p)\,M^2}{Z_2} \qquad (24)$$

The steady operating impedance is

$$Z_0 = \frac{Z_1\,Z_2 - j\,\omega\,(j\,\omega - j\,p)\,M^2}{Z_2} \qquad (25)$$

where $Z_1 = r_1 + j\,\omega\,L_1$ and $Z_2 = r_2 + j\,(\omega - p)\,L_2$. If the transient occurs when the stator winding is symmetrically short-circuited or if it occurs when the stator is connected to a circuit whose resistance and inductance are many times smaller than the similar constants of the motor, the transient terminal pressure of the stator is essentially zero. It is thus evident that the transient impedance is also zero. Equating the transient impedance Z_T to zero gives the characteristic equation for an induction motor and determines the generalized angular velocity of the stator current.

Since $Z_1 = r_1 + m\,L_1$ and $Z_2 = r_2 + (m - j\,p)\,L_2$ equating the transient impedance to zero gives

$(r_1 + m\,L_1)\,[r_2 + (m - j\,p)\,L_2] - m\,(m - j\,p)\,M^2 = O$

Expanding and collecting terms and dividing by $L_1\,L_2$ gives the following quadratic in m:

$$\sigma\,m^2 + (k_1 + k_2 - j\,p\,\sigma)\,m + k_1\,k_2 - j\,p\,k_1 \qquad (26)$$

where $k_1 = r_1/L_1$, $k_2 = r_2/L_2$ and $\sigma = 1 - \frac{M^2}{L_1\,L_2}$

Notice that this characteristic equation for the induction motor is identical with that for a transformer with the exception of two terms, $-j\,p\,\sigma\,m$, and $-j\,p\,k_1$. These terms, however, completely alter the form of the transient. The solution for the generalized angular velocity, m, is:

$$m = -\frac{(k_1 + k_2)}{2\,\sigma} + \frac{j\,p}{2}$$

$$\pm \frac{\sqrt{(k_1 + k_2 - j\,p\,\sigma)^2 - 4\,\sigma\,(k_1\,k_2 - j\,p\,k_1)}}{2\,\sigma} \qquad (27)$$

If $k_1 = k_2$, the quantity under the radical is real and will be negative unless the equivalent resistance is somewhat greater than the equivalent reactance as measured with the rotor blocked, a most unusual con-

dition except possibly in very small motors. Furthermore the decrement $\frac{k_1 + k_2}{2\sigma}$ is very nearly equal to the resistance of the stator winding divided by the equivalent inductance, L_0, as determined from locked saturation test. Thus under ordinary conditions the two values of the generalized angular velocity are approximately:

$$m' = - r_1/L_0 + j\,p \tag{28}$$

$$m'' = - r_1/L_0 + j\,O \tag{29}$$

These are the values given by Doherty and Williamson. The magnitude of the error is best shown by a numerical example. The relative constants of a 25-cycle, 2600-h. p. induction motor are $r_1 = r_2 = L_1 = L_2$ and $\sigma = 0.075$. The equivalent leakage inductance as calculated from these values is relatively $L_0 = 0.0751$. The approximate values of the generalized angular velocity for a speed of 157 radians per sec. are:

$$m' = - 13.31 + j\,157$$

$$m'' = - 13.31 + j\,O$$

The values as calculated from the solution of the characteristic equation are:

$$m' = - 13.33 + j\,155.8$$

$$m'' = - 13.33 + j\,1.2$$

The error in the approximate values in this case at least is very small.

The form of the generalized angular velocity shows that the transient current during short circuit consists of two components, one having a frequency slightly below that corresponding to the speed of the motor, and the other a very low frequency. Notice that the sum of these frequencies always equals that corresponding to the speed of the motor. If the ratios of resistance to synchronous self inductance are not the same for the stator and rotor windings the components of the transient current will decay at different rates, otherwise their rates of diminution are ordinarily equal. During this transient short circuit the angular velocity of the rotor is greater than the angular velocity of the stator currents so that the machine is operating as an induction generator. In this case, the *sum* of the angular velocities of the corresponding stator and rotor component currents is equal to the angular velocity of the rotor. In calculating the performance of an induction machine under steady operating conditions it is customary to use an effective resistance of the stator winding and a true, or ohmic, resistance of the rotor winding. Similarly, it may prove more accurate to use an effective resistance of stator and a true resistance of rotor when calculating m', and, vice versa, a true resistance of stator and an effective resistance of rotor when calculating m''. If, for example, the ratio of effective to true resistance for both stator and rotor is 1.5, the rate of decay of the transient currents is about 25 per cent greater,[3] than would be calculated by using the true resistances. Again, if the ratios of true resistance to synchronous self inductance are the same for both stator and rotor, the rates of decay of the two transient components would be slightly different if effective resistances are substituted for true resistances as suggested.

Having determined the form of the transient it remains only to determine its magnitude. The fundamental principle is that the current in any inductive circuit cannot abruptly change its value. Thus, if the currents in the stator and rotor windings immediately before the transient occurs are represented by the vectors I_{10} and I_{20} in Fig. 18 the vector sum of the currents in these windings immediately after the transient begins must be respectively I_{10} and I_{20}. The case is somewhat different from the single-phase transformer inasmuch as there are now two or more stator or primary circuits and a corresponding number of rotor or secondary circuits in which the instantaneous values of the currents immediately before and after the transient begins must be the same. It has already been pointed out that for any instantaneous values of balanced polyphase currents in symmetrical windings both the currents and the magnetic field which they produce may be represented by *vectors* in phase with each other. If the currents in the stator and rotor windings do not abruptly change at the moment that the transient begins, it is evident that the component magnetic fields they produce in the air gap do not change in magnitude or in position. That is, the vectors which represent the component fields produced by the stator and rotor currents do not change at the moment that the transient begins. Since the current vectors are in phase with the flux vectors they also do not change abruptly. The general relation that holds at the moment that the transient begins is:

$$I_{10} = \bar{I}_1' + \bar{I}_1'' + I_{1s} \tag{30}$$

$$I_{20} = \bar{I}_2' + \bar{I}_2'' + I_{2s} \tag{31}$$

where I_{10} and I_{20} are the vectors representing the stator and rotor currents before the transient begins; $\bar{I}_1'$ and $\bar{I}_1''$ are the generalized vectors representing the two transient components of the stator currents; similarly $\bar{I}_2'$ and $\bar{I}_2''$ are the generalized vectors representing the transient components of the rotor current; I_{1s} and I_{2s} are the vectors which represent the steady currents in the stator and rotor which will exist alone after the transient has disappeared. As it is more convenient if the rotor currents are determined on the basis of a one to one ratio of transformation this will be done throughout. In this case $L_1 = L_2$, at least approximately. The steady operating conditions before and after the transient occurs are sufficient to determine the steady current vectors I_{10}, I_{1s}, etc. The following relations must hold for the transient currents:

$$\bar{I}_1' + \bar{I}_1'' = I_{10} - I_{1s}$$

$$\bar{I}_2' + \bar{I}_2'' = I_{20} - I_{2s}$$

3. A. I. E. E. Transactions, page 525.

If an induction motor or generator is short-circuited on all phases I_{1s} and I_{2s} are both zero since there will ultimately be no current in the machine. If an induction motor or generator is connected to a line when it carries no current, I_{10} and I_{20} are both zero. We shall work out in detail only the first of these cases since nothing is gained in generality by doing more.

Each of the transient components must satisfy the vector relation:

$$(r_1 + m\,L_1)\,\bar{I}_1 + m\,M\,\bar{I}_2 = O$$

and thus we may write:

$$(r_1 + m'\,L_1)\,\bar{I}_1' + m'\,M\,\bar{I}_2' = O \qquad (32)$$

$$(r_1 + m''\,L_1)\,\bar{I}_1'' + m''\,M\,\bar{I}_2'' = O \qquad (33)$$

also at the moment of short circuit

$$\bar{I}_1' + \bar{I}_1'' = I_{10} \qquad (34)$$

and

$$\bar{I}_2' + \bar{I}_2'' = I_{20} \qquad (35)$$

Solving these four simultaneous equations for the components of the transient currents in the stator winding gives:

$$I_1' = \frac{m'\,m''}{m' - m''}\,[M/r_1\,I_{20} + (1/k_1 + 1/m'')\,I_{10}]$$

and

$$\bar{I}_1'' = \frac{m'\,m''}{m'' - m'}\,[M/r_1\,I_{20} + (1/k_1 + 1/m')\,I_{10}]$$

These expressions are readily reduced to understandable forms if suitable approximations are made. If $k_1 = k_2 = k$ the values of m' and m'' are approximately

$$m' = -\,k/\sigma + j\,p \qquad (36)$$

$$m'' = -\,k/\sigma + j\,O \qquad (37)$$

Also

$$M = \sqrt{1 - \sigma}\,L$$

$$= (1 - \sigma/2)\,L \qquad \text{approximately}$$

where L is the synchronous self inductance of either the stator or rotor winding. The approximate values of the transient components become:[4]

$$I_1' = I_{10}/2 - 1/\sigma\,I_n$$

$$I_1'' = I_{10}/2 + 1/\sigma\,I_n$$

The error in these values is well within 10 per cent ordinarily. Notice that the transient currents depend almost entirely upon the no-load current, I_n, and the leakage coefficient, σ. It makes little difference whether short-circuit occurs at no-load or full load. The first of these components rotates at approximately synchronous speed while the second is practically stationary. Each shrinks exponentially at the same rate. The first maximum value of the transient current in any phase is greatest if it occurs at such a time that the transient components lie as nearly as possible in the projection axis for that phase at the moment that the transient begins. For, in that case, about one-half a cycle later the first component will have overtaken the second and the resulting projection on the axis of the phase will have its greatest value. During this time, however, each of the components will have shrunk to $\epsilon^{-\frac{k}{\sigma}\frac{\pi}{p}}$ of their initial values. The first maximum current rush may be to an approximate value of

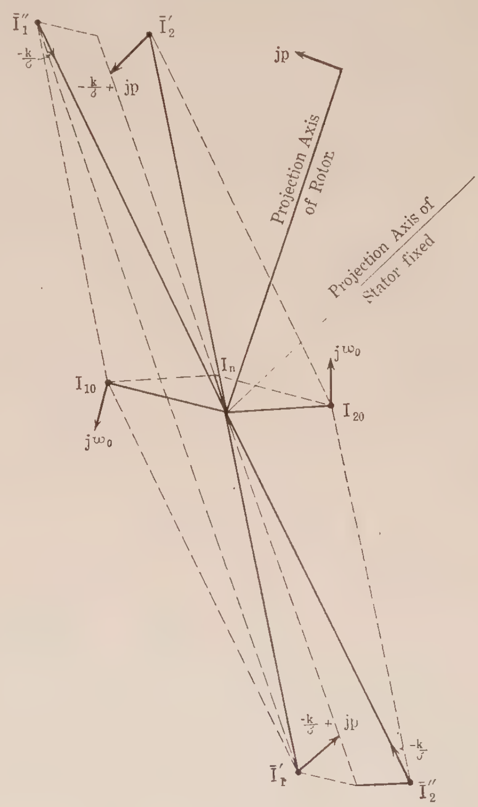

FIG. 18

$$\frac{2\,I_n}{\sigma}\;\epsilon^{-\frac{k}{\sigma}\frac{\pi}{p}} \qquad (38)$$

where I_n is the maximum value of the exciting current before the transient begins. This approximate solution checks with that given by Doherty and Williamson although the latter is in a slightly different form. The vector diagram is given in Fig. 18, which is drawn at the moment that the transient begins. The projection axes of one phase of the stator winding and of one phase of the rotor winding are shown. The former is fixed in position while the latter rotates at a speed

4. More exact solutions for the component currents, based on the approximate values of m are:

$$\bar{I}_1' = \left(1 + j\,\frac{k}{\sigma\,p}\right)\left(I_{10}/2 - \frac{\sqrt{1-\sigma}}{\sigma}\,I_n\right)$$

and

$$\bar{I}_1'' = \left(1 + j\,\frac{k}{\sigma\,p}\right)\left(\frac{1 - j\,\frac{k}{\sigma\,p}}{1 + j\,\frac{k}{\sigma\,p}}\,I_{10}/2 + \frac{\sqrt{1-\sigma}}{\sigma}\,I_n\right).$$

equal to that of the rotor, *viz.*, p radians per sec. When s is the slip, p equals $(1 - s)\ \omega_0$. Before the transient begins only the vectors representing the stator and rotor currents appear. They are rotating at a uniform angular velocity, ω_0. At the moment of short circuit both of these vectors vanish and in their places spring the vectors which represent the transient currents. The arrows at the ends of these vectors represent their angular velocities.

Symmetrical Polyphase and Single-Phase Systems Moving with Respect to Each Other at a Constant Angular Velocity

The analysis of this problem is somewhat more difficult than that of the preceding. When a polyphase winding is acted upon by a rotating magnetic field it reacts and produces another magnetic field which always rotates at the same speed and in the same direction as does the first. This is not true of a single-phase winding, however, and it is herein that the difficulty lies. When a single-phase winding is excited by a rotating magnetic field, there is produced in it

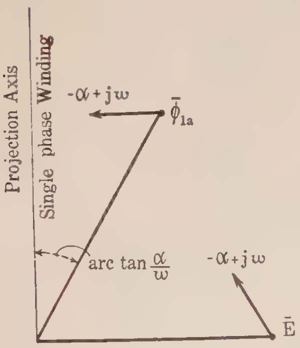

Fig. 19

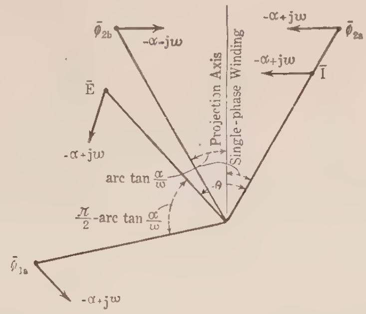

Fig. 20

an alternating current of a frequency corresponding to their relative angular velocities. An alternating current in a single-phase winding produces a magnetic effect that is equivalent to two magnetic fields which rotate in opposite directions with respect to the winding at an angular velocity equal to that of the current in the winding. This well-known method of analysis is ascribed to Ferraris. The magnitude of each of these fields is one-half of the *maximum* value of the actual alternating field produced by the single-phase current.

We have already established the relation that exists between a rotating field and the field which may be produced by its action on a polyphase winding. It now becomes necessary to establish a corresponding relation when the rotating field acts on a single-phase winding. In Fig. 19 let $\bar{\phi}_{1a}$ represent a positively rotating magnetic field which has a complex angular velocity $(-\alpha + j\omega)$. The flux linking the single-phase winding will be a maximum at the moment when $\bar{\phi}_{1a}$ is in the position shown. The generated e. m. f., E, in the winding will be zero at this instant. By the time that $\bar{\phi}_{1a}$ has advanced $(\pi/2 - \text{arc tan}\ \alpha/\omega)$ this generated e. m. f. will be a maximum. The current however will not reach its maximum value until a time still later that is determined by the generalized self impedance of the single-phase winding. At the time that the current is a maximum the vector representing it is arc tan α/ω from the axis of the winding as shown in Fig. 20. At this moment one of the oppositely rotating fields $\bar{\phi}_{2a}$ is coincident with the current and the other, $\bar{\phi}_{2b}$, makes the same angle with but is on the other side

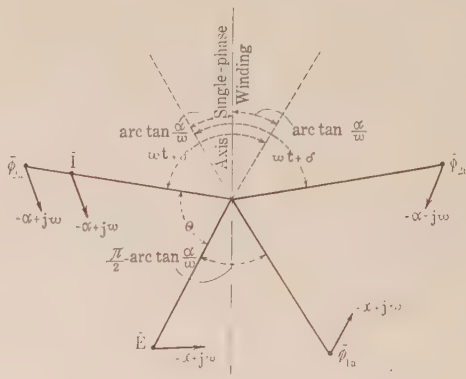

Fig. 21

of the axis of the winding. Of course, the axis of the field due to a single-phase current always coincides with the axis of the winding.

One of these oppositely rotating fields travels at the same speed and in the same direction as does the initial field, $\bar{\phi}_{1a}$, while the other travels at the same speed but in the opposite direction. The condition at a time angle $\omega t + \delta$ after the current in the single-phase winding is a maximum is shown in Fig. 21. The oppositely rotating fields are represented by the vectors

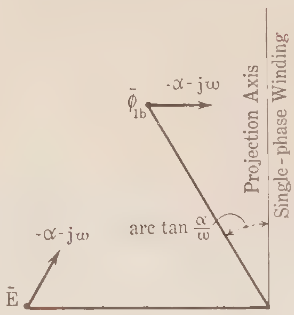

Fig. 22

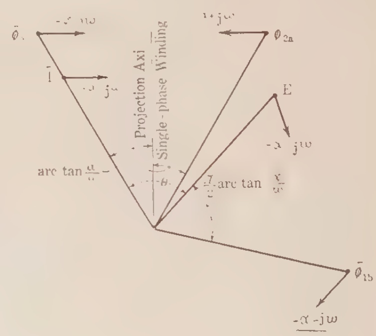

Fig. 23

$\bar{\phi}_{2a}$ and $\bar{\phi}_{2b}$: the subscripts a and b indicate the direction of rotation. The constant phase relation between $\bar{\phi}_{1a}$ and $\bar{\phi}_{2a}$ will be determined presently.

If the first magnetic field had been rotating negatively with a complex angular velocity of $(-\alpha - j\omega)$ the flux linking the single-phase winding would have been maximum at the moment shown in Fig. 22. By the time the current had reached its maximum value this field would have reached the position indicated in

Fig. 23. The oppositely rotating components of the single-phase field are now shown at $\bar{\phi}_{2a}$ are $\bar{\phi}_{2b}$. At a time angle $\omega\, t + \delta$ later the vectors shown in Fig. 23 will have moved to the positions shown in Fig. 24. It is important to observe that the oppositely rotating components of the single-phase field are exactly the same in Fig. 21 and in Fig. 24. That is, as far as the reaction produced in the single-phase winding is concerned, there is no difference between positively and negatively rotating fields provided they are always conjugate with respect to the axis of the single-phase winding. In the case of polyphase windings we have seen that positively and negatively rotating magnetic fields produce quite different effects.

A magnetic field that rotates *positively* with respect to a polyphase winding excites the latter so that it in turn produces another field which rotates *positively* and which lags behind the first by an angle determined by the relative generalized angular velocity of the rotating field and the polyphase winding, and the resistance and synchronous self inductance of the latter. The reaction of the polyphase winding is

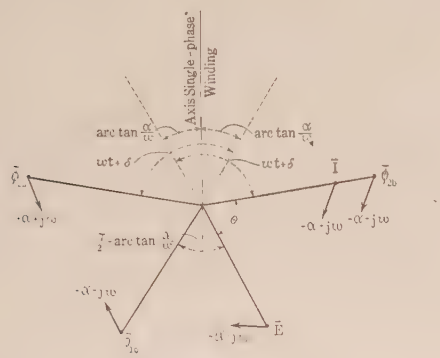

Fig. 24

often analyzed in the following manner: The alternating current that is generated in each phase of the polyphase winding produces two component fields that are rotating in opposite directions with respect to the winding. Those component fields due to the different phases which rotate opposite to the exciting field sum up to zero if the phase circuits are symmetrical. The other component fields that rotate in the same direction as the exciting field are in space phase with each other and their resultant is thus n times any one component; where n is the number of phases of the polyphase winding. That is, we may consider that the current in each phase of a polyphase winding consists of two equal components, hereafter designated by the subscripts a and b, each equal to *one-half* of the *maximum phase current*. These two component currents produce equal but oppositely rotating magnetic fields. If the winding were single-phase each of these magnetic fields would exist, but with a symmetrical polyphase winding only the fields exist which rotate in the same direction as does the exciting field. Those that rotate in the opposite direction neutralize one another, so that their resultant is zero.

Let M_1 be the e. m. f. generated in one phase of the polyphase winding by *one ampere* of *either* the a or b component of the single-phase current when varying at the rate of one ampere per second. Similarly let M_n be the e. m. f. generated in the single-phase winding by one ampere of the a component of the polyphase current, provided that is the one which produces a magnetic field, when varying at the rate of one ampere per second. Thus defined the n-phase mutual inductance is n times the single-phase mutual inductance. If the single-phase winding is supplied with an alternating current having an angular velocity of ω and the winding is rotated at this same velocity, ω, with respect to the polyphase winding, one of the oppositely rotating fields due to the single-phase current will be stationary with respect to the polyphase winding and thus will generate no e. m. f. in it. The other field will rotate at a relative angular velocity of $2\,\omega$ and generate an e. m. f., E, in each phase of the polyphase winding. If the single-phase current is I, the single-phase mutual inductance is $M_1 = \dfrac{E}{2\,\omega\, I/2}$. If the single- and polyphase windings are fixed with respect to each other and one phase of the latter is directly opposite the former, the oppositely rotating fields produce equal e. m. fs. in time phase with each other in this phase of the polyphase winding. If E is still the e. m. f. generated in this phase of the polyphase winding the e. m. f. due to *one* of the component fields is $E/2$ and the single-phase mutual inductance is as before $M_1 = \dfrac{E}{2\,\omega\, I/2}$; where I and ω are the current and its angular velocity in the single-phase winding. If the two windings are fixed with respect to each other and balanced currents of I amperes per phase are supplied to the polyphase winding the polyphase mutual inductance is the e. m. f. generated in the single-phase winding divided by $\dfrac{\omega\, I}{2}$; where ω is the angular velocity of the polyphase currents and I is the current per phase. Thus measured, the n-phase mutual inductance will be n times the single-phase inductance.

Let us assume that we have a three-phase winding fixed in position and a single-phase winding which is rotating in the positive direction at an angular velocity of p radians per second. If the single-phase winding carries a current having an angular velocity of ω radians per second there will be produced in the air-gap two rotating fields, one traveling in the positive direction at an angular velocity of $(\omega + p)$ and the other in the negative direction at a velocity of $(\omega - p)$ radians per second. If p is greater than ω both of these fields travel in the positive direction. The following relations can be worked out on the assumption that ω is either greater or less than p. In accordance with the established custom when analyzing polyphase induction

motors and generators, we will choose the first of these assumptions, *viz.*, that ω is greater than p.

The alternating current in the single-phase winding having an angular velocity, ω, produces two oppositely rotating fields each having this same angular velocity. The single-phase winding, having a positive angular velocity of p radians per second, gives to each of these fields an added angular velocity, so that one rotates positively with an angular velocity of $\omega + p$ and the other negatively with angular velocity of $\omega - p$ radians per second. Each of these fields produces by its action on the polyphase winding a rotating field which has the same angular velocity. This is illustrated in Fig. 25. In this figure A_1 represents the fixed axis of one phase of the polyphase winding, and A_2 represents the axis of the single-phase winding; the latter having a positive angular velocity of p radians per second. The oppositely rotating fields due to the single-phase current, which has a complex angular velocity of $-\alpha + j\,\omega$ radians per second, are represented by the vec-

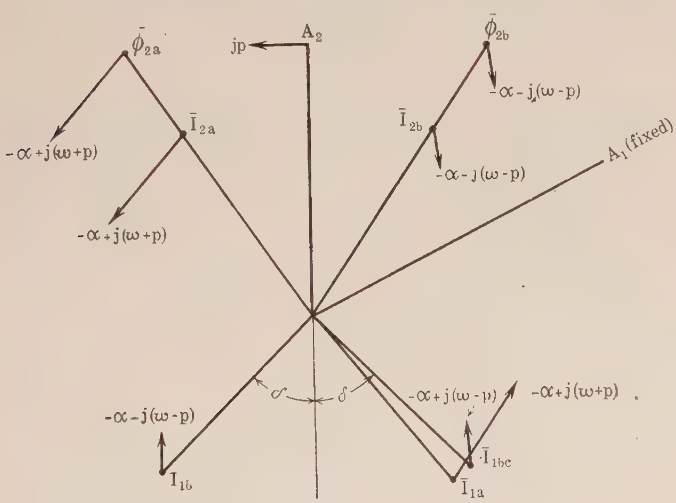

FIG. 25

tors $\bar\phi_{2a}$ and $\bar\phi_{2b}$. The former has an angular velocity of $-\alpha + j(\omega + p)$ and the latter a velocity of $-\alpha - j(\omega - p)$ radians per second. Since these component fields are proportional to the current in the single-phase winding, this current can be divided into similar components as indicated in the figure, $\bar I_{2a}$ and $\bar I_{2b}$. Observe that each of these component currents is one-half of the maximum value of the single-phase current, and that at any moment the actual current in the single-phase winding is their vector sum. The first of these rotating fields, $\bar\phi_{2a}$, produces a current in the short-circuited polyphase winding $\bar I_{1a}$ where

$$I_{1a} = \frac{-\bar I_{2a} M_1 (m + j\,p)}{r_1 + (m + j\,p) L_1}$$

$$= \frac{-\bar I_{2a} M_1 (m + j\,p)}{Z_{1\,(m+jp)}} \tag{39}$$

M_1 is the single-phase mutual inductance, $m = -\alpha + j\,\omega$ is the generalized angular velocity of the single-phase current, r_1 and L_1 are respectively the resistance and synchronous self inductance of the polyphase winding. The other rotating field $\bar\phi_{2b}$ produces a current in the short-circuited polyphase winding, $\bar I_{1b}$, which has a *negative* angular velocity of $\omega - p$ radians per second. In this case the current is:

$$\bar I_{1b} = \frac{-\bar I_{2b} M_1 [-\alpha - j(\omega - p)]}{r_1 + [-\alpha - j(\omega - p)] L_1} \tag{40}$$

Each of these polyphase currents produces two oppositely rotating component currents in the single-phase winding. The sum of the components which rotate in the same direction must of course be equal to the initial components rotating in the corresponding direction that were assumed to exist, *viz.*, $\bar I_{2a}$ and $\bar I_{2b}$. By the principle already established the rotating field due to $\bar I_{1b}$, produces the same effect in the single-phase winding as would a current of the same magnitude which rotates positively and is always conjugate to $\bar I_{1b}$ with respect to the axis of the single-phase winding. It is readily seen that this conjugate current, $\bar I_{1bc}$, is

$$\bar I_{1bc} = \frac{-\bar I_{2a} M_1 [-\alpha + j(\omega - p)]}{r_1 + [-\alpha + j(\omega - p)] L_1}$$

$$= \frac{-\bar I_{2a} M_1 (m - j\,p)}{Z_{1\,(m-jp)}} \tag{41}$$

The stator current $\bar I_{1a}$ and the conjugate current $\bar I_{1bc}$, which replaces $\bar I_{1b}$, both rotate positively and their resultant effect on the single-phase winding is thus the same as the effect of their vector sum. The positively rotating component of the single-phase current is thus given by:

$$2\,\bar I_{2a} = \frac{-(\bar I_{1a} + \bar I_{1bc})\, 3\, M_1 (-\alpha + j\,\omega)}{r_2 + (-\alpha + j\,\omega) L_2}$$

$$\bar I_{2a} = \frac{-(\bar I_{1a} + \bar I_{1bc})\, 3/2\, M_1\, m}{Z_{2\,m}} \tag{42}$$

These characteristic equations may be written thus:

$$\bar I_{1a} Z_{1\,(m+jp)} + \bar I_{2a} M_1 (m + j\,p) = 0 \tag{43}$$

$$\bar I_{1bc} Z_{1\,(m-jp)} + \bar I_{2a} M_1 (m - j\,p) = 0 \tag{44}$$

$$\bar I_{2a} Z_{2\,(m)} + (\bar I_{1a} + \bar I_{1bc}) \frac{3\,M_1}{2}\, m = 0 \tag{45}$$

In these equations it is assumed that any impedance outside the armature and field circuits is negligible, otherwise the zeros at the right of the equality signs would be replaced by the proper *fall* in *terminal pressure.*

If $\bar I_{1a}$ and $\bar I_{1bc}$ as determined by the first two equations are substituted in the third equation, the latter becomes, on dividing by I_{2a}

$$Z_{2\,(m)} - 3/2\, M_1\, m \left(\frac{M_1 (m + j\,p)}{Z_{1\,(m+jp)}} + \frac{M_1 (m - j\,p)}{Z_{1\,(m-jp)}} \right) = 0 \tag{46}$$

If the values of the impedances are substituted, this reduces to the following cubic in m:

$$m^3 + \frac{(k_1(1+\sigma) + k_2)\, m^2}{\sigma} + \frac{(k_1^2 + 2\,k_1\,k_2 + \sigma\,p^2)\,m}{\sigma} + \frac{(k_1^2 + p^2)\,k_2}{\sigma} = O \qquad (47)$$

where $k_1 = r_1/L_1$, $k_2 = r_2/L_2$ and $\sigma = 1 - \dfrac{3\,M_1^2}{2\,L_1\,L_2}$

r_1 and r_2 are the resistances of one phase of the polyphase winding and of the single-phase winding; L_1 and L_2 are the synchronous self-inductance of the polyphase winding, and the self inductance of the single-phase winding. At least one root of a cubic equation must be real and since the coefficients are all positive this root must be negative. This indicates that one of the components of the single-phase current is a diminishing direct current. The other roots of the cubic equation are conjugate imaginaries. This indicates two alternating currents, having positive and negative angular velocities but the same rate of diminution. In the polyphase winding, however, the three components of the current will all have different angular velocities. The first component of the single-phase current will produce a current having an angular velocity of p radians per second and the same rate of diminution that it itself has. The second component of the single-phase current, having a positive angular velocity will produce a current which has an angular velocity of approximately $2\,p$ radians per second. The third component of the single-phase current having a negative angular velocity, produces a current in the polyphase winding of very small angular velocity. The sum of the angular velocities of these two latter components of the polyphase current is exactly $2\,p$, and each diminishes at the same rate as does the alternating current in the single-phase winding.

A literal cubic equation is practically impossible to solve but if numerical values are given to k_1, k_2 and σ, the real root can be found to any degree of approximation by Horner's method. The equation may then be reduced to a quadratic, the roots of which can be readily found. Approximate values of the roots may be found as follows: The largest term in any of the coefficients is p^2. With a 60-cycle machine this would be 142,122. The ratios of resistance to self-inductance k_1 and k_2, are of the order ten, while σ is of the order one-tenth. For these values of k_1, k_2 and σ the real root of the characteristic equation is approximately

$$m = -\,k_2/\sigma \qquad (48)$$

The degree of approximation of course depends upon the values of the constants. If $k_1 = k_2 = 1.0$, $\sigma = 0.1$ and $p = 377$;

$$m = -\,10.06$$

whereas the approximate value would be

$$m = 10.0$$

In this case the error is about one-half of one per cent; which is better than the analysis warrants.

Since the sum of the roots must be the coefficient of m^2 in the characteristic equation with its sign changed and since the remaining roots are conjugate imaginaries of the form $-\,\alpha_2 \pm j\,\omega$ we have

$$-\,k_2/\sigma - 2\,\alpha_2 = -\frac{k_1(1+\sigma) + k_2}{\sigma} \qquad (49)$$

That is:

$$\alpha_2 = -\frac{k_1(1+\sigma)}{2\,\sigma} \qquad (50)$$

Furthermore since the product of the roots is equal to the last term in the characteristic equation we have:

$$\alpha_1(\alpha_2^2 + \omega^2) = (k_1^2 + p^2)\,k_2/\sigma$$

From this, the approximate value of ω is seen to be

$$\omega = \sqrt{p^2 - (\alpha_2^2 - k_1^2)}$$

$$= p - \frac{\alpha_2^2 - k_1^2}{2\,p} \quad \text{approximately} \qquad (51)$$

For the assumed values of k_1, k_2, σ and p the calculated values of α_2 are ω are:

$$\alpha_2 = 5.497$$

and

$$\omega = 376.73$$

For the same values of the constants the approximate values of α_2 and ω are:

$$\alpha_2 = \frac{1 \times 1.12}{2 \times 0.1} = 5.50$$

$$\omega = 377 - \frac{5.5^2 - 1}{2 \times 377}$$

$$= 376.96$$

It is readily appreciated that for such values of the constants as were chosen the roots are approximately

$$m' = -\,k_2/\sigma \qquad (52)$$

$$m'' = -\frac{k_1(1+\sigma)}{2\,\sigma} \pm j\,p \qquad (53)$$

It may be desirable, however, to extend the analysis so that it will apply to the case in which it is necessary to consider the constants of circuits outside of the machine itself. In that event the approximate values of the roots may not be sufficiently accurate. Again if the constants are considerably larger, as for example:

Let $k_1 = 15$, $k_2 = 20$, $\sigma = 0.15$ and $p = 377$ the actual values of m are:

$$m' = -\,143.2 + j\,o$$
$$m'' = -\,52.57 \pm j\,360.3$$

The approximate values of m are:

$$m' = -\,133.3$$
$$m'' = -\,57.5 \pm j\,373$$

In this case the error in the approximate calculation is quite considerable.

The general principle that determines the magnitude of the various component currents is that the resulting distribution of magnetic field in all parts of the machine

cannot abruptly change, and what is even more important the component fields due to the different currents cannot abruptly change. That is, in mathematical language, the magnetic field at every point is a continuous function of the time, and since the magnetic fields are assumed to be proportional to the currents, the latter are also continuous functions of the time. If it were possible to construct mutually inductive circuits which had a leakage coefficient of zero, the currents in these circuits might abruptly change, *i. e.*, they might be discontinuous functions.

In order to illustrate the method of determining the component currents we will calculate their approximate values when the alternator is suddenly short-circuited. The general method of treating the single-phase current is to represent it by pairs of oppositely rotating vectors. In the present problem there are two such pairs one having no velocity and the other an angular velocity of p radians per second. That is, the transient current $\bar{I}_{2T}$ in the single-phase winding may be equated to four components:

$$\bar{I}_{2T} = \bar{I}_{2a}' + \bar{I}_{2b}' + \bar{I}_{2a}'' + \bar{I}_{2b}'' \qquad (54)$$

$\bar{I}_{2a}'$ and $\bar{I}_{2b}'$ are conjugate and have zero velocity with respect to the single-phase axis. $\bar{I}_{2a}''$ and $\bar{I}_{2b}''$ are conjugate and have an angular velocity of approximately p radians per second with respect to the same axis. Each of these transient components in the single-phase winding is the cause of a corresponding component in the polyphase winding. Thus, similarly:

$$\bar{I}_{1T} = \bar{I}_{1a}' + \bar{I}_{2b}' + \bar{I}_{1a}'' + \bar{I}_{1b}'' \qquad (55)$$

$\bar{I}_{1a}'$ and $\bar{I}_{1b}'$ both have the same angular velocity of p radians per second, $\bar{I}_{1a}''$ has an angular velocity of approximately $2\,p$ and I_{1b}'' an angular velocity of approximately zero radian per second.

The fundamental relation at the moment of short circuit is that:

$$I_{10} = \bar{I}_{1T} + I_{1s} \qquad (56)$$

and

$$I_{20} = \bar{I}_{2T} + I_{2s} \qquad (57)$$

where I_{10} is the current in the polyphase winding, before short circuit and I_{1s} is the steady current after the transient $\bar{I}_{1T}$ occasioned by the short circuit has disappeared. I_{20} and I_{2s} are similar values for the single-phase winding.

If the field excitation is not changed at or after short circuit $I_{20} = I_{2s}$ and thus the transient current in the single-phase winding must be zero at the moment of short circuit. Since the components of the single-phase current are conjugate in pairs it follows that at the moment of short circuit:

$$I_{2a}' = -\,I_{2a}'' \qquad (58)$$

and

$$I_{2b}' = -\,I_{2b}'' \qquad (59)$$

The corresponding pairs of single- and polyphase component currents must satisfy the two equations (**43**) and (**44**), the a components satisfying (**43**) and the b components, (**44**). Thus:

$$I_{1a}'\,[r_1 + (-\,k_2/\sigma + j\,p)\,L_1] + I_{2a}'\,M_1\,(-\,k_2/\sigma + j\,p) = O \qquad (60)$$

$$I_{1b}'\,[r_1 + (-\,k_2/\sigma + j\,p)\,L_1] + I_{2b}'\,M_1\,(-\,k_2/\sigma + j\,p) = O \qquad (61)$$

$$I_{1a}''\left[r_1 + \left(-\,k_1\frac{(1+\sigma)}{2\,\sigma} + j\,2\,p\right)L_1\right] + I_{2a}''\,M_1\left(-\,k_1\frac{(1+\sigma)}{2\,\sigma} + j\,2\,p\right) = O \qquad (62)$$

$$I_{1b}''\left(r_1 + (-\,k_1\frac{(1+\sigma)}{2\,\sigma}\;L_1\right) + I_{2b}''\,M_1\left(-\,k_1\frac{(1+\sigma)}{2\,\sigma}\right) = O \qquad (63)$$

If each of these equations is divided by L_1, it will be seen that since k_1 is much smaller than k_1/σ, k_2/σ or p, the following relations between the polyphase and single-phase components are approximately true:

$$\bar{I}_{1a}' = -\,M_1/L_1\,\bar{I}_{2a}'$$
$$\bar{I}_{1b}' = -\,M_1/L_1\,\bar{I}_{2b}'$$
$$\bar{I}_{1a}'' = -\,M_1/L_1\,\bar{I}_{2a}''$$

but

$$\bar{I}_{1b}'' = -\,M_1/L_1\frac{(1+\sigma)}{(1-\sigma)}\,\bar{I}_{2b}''$$

If the conditions set forth in equations (**55**), (**58**) and (**59**) are applied to these four equations we have:

$$\bar{I}_{1T} = M_1/L_1\frac{2\,\sigma}{1-\sigma}\,I_{2b}' \qquad (64)$$

If it is deemed necessary a more accurate value of I_{2b}' can be calculated by substituting in equations (**60**) to (**63**) inclusive the actual values of the generalized angular velocity as determined by equation (**47**) and by recognizing that I_{2a}' and I_{2b}' are conjugate with respect to the single-phase axis.

Since the current in the polyphase winding before short circuit is much smaller than the steady short-circuit current:

$\bar{I}_{1T} = -\,I_{1s}$ approximately, at the moment of short circuit. The steady short-circuit current is calculated by dividing the e. m. f. generated in the polyphase winding on open circuit by the synchronous impedance. The open circuit e. m. f. is

$$E = -\,j\,p\,M_1\,I_{20} \qquad (65)$$

Since the resistance is much less than the synchronous reactance the steady short-circuit current is approximately.

$$I_{1s} = -\frac{j\,p\,M_1\,I_{20}}{j\,p\,L_1} = -\,M_1/L_1\,I_{20} \qquad (66)$$

From this it follows that:

$$I_{2b}' = I_{20}\frac{(1-\sigma)}{2\,\sigma} \qquad (67)$$

The direct-current component of the single-phase current has an initial value of $I_{2a}' + I_{2b}'$ which is $I_{20} \dfrac{(1-\sigma)}{\sigma}$. The alternating component of the single-phase current is equal and opposite to this initially, but one-half cycle later the vectors representing all of the component currents are in phase. During this time, however, the direct and alternating components have shrunk different amounts. The first maximum value of the single-phase current will be, approximately:

$$I_{20} \frac{(1-\sigma)}{\sigma} \left\{ \epsilon^{-\frac{k_2}{\sigma}\frac{\pi}{p}} + \epsilon^{-\frac{k_1(1+\sigma)}{2\sigma}\frac{\pi}{p}} \right\} \quad (68)$$

For $k_1 = k_2 = 1$, $\sigma = 0.1$, this is 17 I_{20}.

The component of the polyphase current which has an angular velocity of p radians per second is $\bar{I}_{1a}' + \bar{I}_{1b}'$ which initially equals $\dfrac{1-\sigma}{\sigma} I_{1s}$. The component which has an angular velocity of approximately $2p$ is $\bar{I}_{1a}''$ which initially equals $-\dfrac{1-\sigma}{2\sigma} I_{1s}$. The component which has a very small angular velocity is I_{1b}'' which initially equals $-\dfrac{1+\sigma}{2\sigma} I_{1s}$. The first of these components shrinks at a rate of k_2/σ while each of the others shrinks at a rate of $\dfrac{k_1(1+\sigma)}{2\sigma}$. Notice that initially the first component is opposite in phase to each of the others. Thus one-half cycle after the transient begins, the three components will be in phase. If the transient begins at such a time that the steady short-circuit current in one phase would naturally be passing through its maximum value, this phase will carry the maximum possible transient current one-half cycle later. This maximum transient current is approximately:

$$I_{1s}\left[\frac{1-\sigma}{\sigma}\,\epsilon^{-\frac{k_2}{\sigma}\frac{\pi}{p}} + \frac{1}{\sigma}\,\epsilon^{-k_1\frac{(1+\sigma)}{2\sigma}\frac{\pi}{p}}\right] \quad (69)$$

for $k_1 = k_2 = 1$, $= 0.1$ this is 18 I_{1s}, *i. e.* eighteen times the maximum value of the steady short circuit current.

Two Single-Phase Windings Having A Constant Relative Angular Velocity

A current of angular velocity ω in one single-phase winding produces in the other winding currents having angular velocities of $\omega + p$ and $\omega - p$; where p is the relative angular velocity of the two windings. Each of these currents reacts on the first winding and produces additional currents having angular velocities of $\omega + 2p$ and $\omega - 2p$. These currents in turn produce others in the second winding having angular velocities of $\omega + 3p$ and $\omega - 3p$, and so on ad infinitum. It is then evident that the solution of this problem cannot be reached by the method here developed unless all but a few of the component currents are neglected. The solution will not be attempted at this time.

Carson[5] has suggested a functional form of solution of this problem and Dreyfus[6] also gives a solution based on certain assumptions.

In conclusion the writer hardly needs to say that it has been his sole purpose to show how certain low-frequency transient conditions in electric machinery may be analyzed by a vector method. Before accurate results can be obtained by this method considerable experimental work is probably necessary in order to determine the most satisfactory methods of measuring the required constants. An interesting development would be the solution of the transient conditions in certain unsymmetrical arrangements of polyphase machines similar to those so ably discussed by Mr. Fortescue.[7]

Transient conditions may be the result of a variety of causes, one of which is short circuit. The vector method, however, is equally applicable in any case in which the original premises are reasonably true. The actual working out of a numerical solution is rather complex and this has been purposely avoided in order that the general principles might not be obscured a mass of calculation. Furthermore, it seemed best at this time not to attempt to generalize the theory and present it in such form that it would apply to combinations of electric machines that might even be unsymmetrical.

Appendix

For those who are interested in comparing the vector method of solution with the differential equations which apply to these problems the following development is given.

Consider a symmetrically wound three-phase induction motor having Y-connected stator and rotor phases as shown diagrammatically in Fig. 26. The stator and rotor currents are represented by the letters x and y respectively and their assumed positive directions are indicated by the arrows. Fig. 27 shows a development of the air gap. The progression of the phases, 1, 2 and 3 is toward the right for both stator and rotor, and the latter moves at a constant angular velocity of p radians per second toward the right.

Let r_1, r_2, L'_1 and L_2' represent the resistances and self-inductances of one phase of stator and rotor respectively.

Let M_x represent the mutual inductance between any

5. Bibliography No. 7.
6. Bibliography No. 4.
7. A. I. E. E. Vol. XXXVII, p. 1027.

two phases of the stator. Due to symmetry these three mutual inductances are equal.

Let M_y represent the mutual inductances between any two phases of the rotor. These mutual inductances are likewise equal.

Let $2/3\,M$ represent the maximum value of the mutual inductance between one phase of the stator and one phase of the rotor. At a time when the angular

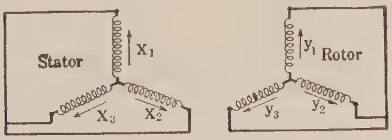

Fig. 26

displacement of these phases of stator and rotor is $p\,t$ the momentary value of this mutual inductance is $2/3\,M\cos p\,t$, if the space distribution of the air-gap flux density is sinusoidal. This assumption of a sinusoidal distribution of flux density is not much in error if the motor is well designed. It is also necessary to assume that r_1, r_2, L_1', L_2', M_x, M_y and $2/3\,M$ are constant. This is commonly done in engineering practise.

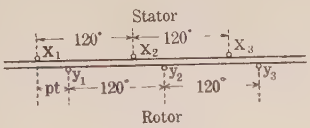

Fig. 27

With the stator phases short-circuited as indicated in Fig. 26 the following differential equations may be written,—considering first phases 1 and 2 and then phases 2 and 3.

$$\Big\{ r_1 x_1 + L_1' \frac{d\,x_1}{d\,t} - M_x \frac{d\,x_2}{d\,t} - M_x \frac{d\,x_3}{d\,t} + \frac{d}{d\,t}\Big[y_1 \frac{2}{3} M \cos p\,t + y_2 \frac{2}{3} M \cos (p\,t + 120°) + y_3 \frac{2}{3} M \cos (p\,t + 240°) \Big] \Big\}$$
$$- \Big\{ r_1 x_2 + L_1' \frac{d\,x_2}{d\,t} - M_x \frac{d\,x_3}{d\,t} - M_x \frac{d\,x_1}{d\,t} + \frac{d}{d\,t}\Big(y_2 \frac{2}{3} M \cos p\,t + y_3 \frac{2}{3} M \cos (p\,t + 120°) + y_1 \frac{2}{3} M \cos (p\,t + 240°) \Big\} = 0 \qquad (1)$$

There is a negative sign before M_x for the reason that positive currents in phases 2 and 3, for example, produce a flux through phase 1 which is opposite in direction to the flux that phase 1 produces through itself.

The equation which applies to phases 2 and 3 is:

$$\Big\{ r_1 x_2 + L_1' \frac{d\,x_2}{d\,t} - M_x \frac{d\,x_3}{d\,t} - M_x \frac{d\,x_1}{d\,t} + \frac{d}{d\,t}\Big[y_2 \frac{2}{3} M \cos p\,t + y_3 \frac{2}{3} M \cos (p\,t + 120°) + y_1 \frac{2}{3} M \cos (p\,t + 240\ ) \Big] \Big\}$$
$$- \Big\{ r_1 x_3 + L_1' \frac{d\,x_3}{d\,t} - M_x \frac{d\,x_1}{d\,t} - M_x \frac{d\,x_2}{d\,t} + \frac{d}{d\,t}\Big[y_3 \frac{2}{3} M \cos p\,t + y_1 \frac{2}{3} M \cos (p\,t + 120°) + y_2 \frac{2}{3} M \cos (p\,t + 240°) \Big] \Big\} = 0 \qquad (2)$$

Since the sums of the stator and rotor currents are each equal to zero, we may substitute:

$$x_3 = - x_1 - x_2 \quad \text{and} \quad y_3 = - y_1 - y_2$$

Also replace $L_1' + M_x$ by L_1. Multiply the second equation by 2 and add it to the first; again, subtract the second equation from the first. The results of these operations are respectively:

$$r_1 x_1 + L_1 \frac{d\,x_1}{d\,t} + \frac{2}{\sqrt{3}} M \frac{d}{d\,t} \big[y_1 \cos (p\,t + 30\ ) + y_2 \cos (p\,t + 90°) \big] = 0 \qquad (3)$$

$$r_1 x_2 + L_1 \frac{d\,x_2}{d\,t} + \frac{2}{\sqrt{3}} M \frac{d}{d\,t} \big[y_1 \cos (p\,t - 90°) + y_2 \cos (p\,t - 30°) \big] = 0 \qquad (4)$$

By a similar procedure differential equations may be written for phases 1 and 2 of the rotor. These equations will be found to be similar to (3) and (4) except that the signs before the phase angles will be reversed. Thus we will find that:

$$r_2 y_1 + L_2 \frac{d\,y_1}{d\,t} + \frac{2}{\sqrt{3}} M \frac{d}{d\,t} \big[x_1 \cos (p\,t - 30°) + x_2 \cos (p\,t - 90°) \big] = 0 \qquad (5)$$

$$r_2 y_2 + L_2 \frac{d\,y_2}{d\,t} + \frac{2}{\sqrt{3}} M \frac{d}{d\,t} \big[x_1 \cos (p\,t + 90°) + x_2 \cos (p\,t + 30°) \big] = 0 \qquad (6)$$

The following treatment was suggested to the author by Dr. F. L. Hitchcock as being the simplest method of reducing these equations to one containing a single variable.

Let $\quad r_1 x_1 + L_1 \dfrac{d\,x_1}{d\,t} = Z_1 x_1$

(Z_1 is an impedance operator)

Similarly $\quad r_1 x_2 + L_1 \dfrac{d\,x_2}{d\,t} = Z_1 x_2$

Also $\quad r_2 y_1 + L_2 \dfrac{d\,y_1}{d\,t} = Z_2 y_1$

And $\quad r_2 y_2 + L_2 \dfrac{d\,y_2}{d\,t} = Z_2 y_2$

If D and D^{-1} represent the direct and inverse differential operators, we shall have on integrating equations (3) and (4):

$$D^{-1} Z_1 x_1 + 2/\sqrt{3}\, M \big[y_1 \cos (p\,t + 30°) + y_2 \cos (p\,t + 90° \big] = 0 \qquad (7)$$

$$D^{-1} Z_1 x_2 + 2/\sqrt{3}\, M \big[y_1 \cos (p\,t - 90°) + y_2 \cos (p\,t - 30° \big] = 0 \qquad (8)$$

Solve these two equations for y_1 and y_2

$$y_1 = \frac{2}{\sqrt{3}\,M}\{\cos(p\,t + 90°)\,D^{-1} Z_1 x_2 - \cos(p\,t - 30\ )\,D^{-1} Z_1 x_1\} \qquad (9)$$

$$y_2 = \frac{2}{\sqrt{3}\,M}\{\cos(p\,t - 90°)\,D^{-1} Z_1 x_1 - \cos(p\,t + 30°)\,D^{-1} Z_1 x_2\} \qquad (10)$$

Differentiation of equation (**9**) gives:

$$\frac{d\,y_1}{d\,t} = \frac{2}{\sqrt{3}\,M}\{\cos(p\,t + 90°)\,Z_1 x_2 - p\sin(p\,t + 90°)\,D^{-1} Z_1 x_2 - \cos(p\,t - 30°)\,Z_1 x_1 + p\sin(p\,t - 30°)\,D^{-1} Z_1 x_1\}$$

The expression for y_2 may be differentiated in a like manner.

If the values of y_1, y_2, $\frac{d\,y_1}{d\,t}$ and $\frac{d\,y_2}{d\,t}$ are now substituted in equations (**5**) and (**6**), the resulting equations may be written as follows:

In order to simplify the writing of these equations let:

$$\begin{array}{ll} \cos(p\,t - 30°) = a & \sin(p\,t - 30°) = a_1 \\ \cos(p\,t + 30°) = b & \sin(p\,t + 30°) = b_1 \\ \cos(p\,t - 90°) = c & \sin(p\,t - 90°) = c_1 \\ \cos(p\,t + 90°) = d & \sin(p\,t + 90°) = d_1 \end{array}$$

Equation (**5**) becomes:

$$\{(-r_2 a + p L_2 a_1)\,D^{-1} Z_1 - L_2 a Z_1 + M^2 (a D - p a_1)\}\,x_1 + \{(r_2 d - p L_2 d_1)\,D^{-1} Z_1 + L_2 d + M^2 (c D - p c_1)\}\,x_2 = 0 \qquad (11)$$

Equation (**6**) becomes:

$$\{(r_2 c - L_2 p c_1)\,D^{-1} Z_1 + L_2 c Z_1 \;(-r_2 b + L_2 p b_1)\,D^{-1} Z_1 - L_2 b Z_1 + M^2 (d D - p d_1)\}\,x_1 + + M^2 (b D - p b_1)\}\,x_2 = 0 \qquad (12)$$

In the process of eliminating x_1 and x_2 from equations (**11**) and (**12**) all of the harmonic terms in the coefficients vanish, giving as a final result:

$$(r_2^2 + L_2^2 p^2)(D^{-1} Z_1)^2 + L_2^2 Z_1^2 + (D^2 + p^2) M^4 + 2 r_2 L_2 Z_1 D^{-1} Z_1 - 2 (r_2 D + p^2 L_2) M^2 D^{-1} Z_1 - 2 M^2 L_2 Z_1 D = 0 \qquad (13)$$

Differentiate this equation twice, collect the terms in descending powers of D and after dividing each term by $L_1^2 L_2^2$, let $1 - \frac{M^2}{L_1 L_2} = \sigma$, $r_1/L_1 = k_1$ and $r_2/L_2 = k_2$. This gives:

$$\sigma^2 D^4 + 2\sigma(k_1 + k_2) D^3 + [(k_1 + k_2)^2 + 2\sigma k_1 k_2 + p^2 \sigma^2] D^2 + [2 k_1 k_2 (k_1 + k_2) + 2 p^2 k_1 \sigma] D + k_1^2 (k_2^2 + p^2) = 0 \qquad (14)$$

If equation (**26**) in the body of the paper is written for the conjugate roots, *i. e.*, for a negative value of the rotor angular velocity it would be:

$$\sigma m^2 + (k_1 + k_2 + j p \sigma) m + k_1 k_2 + j p k_1 = 0 \qquad (26_1)$$

The product of equations (**26**) and (**26**$_1$) will contain all four roots, and will be found to be identical with the differential equation (**14**).

This proves that the two methods are identical in regard to the results they produce, and that, of the two, the vector method is much less laborious. Furthermore, it is much simpler to determine the constants of integration by the vector method.

Synchronous Alternator

In this case there is only one phase on the rotor, *viz.* the field winding. Making the same assumptions in regard to the resistances and inductances as were made before, the following differential equations may be written:

$$r_1 x_1 + L_1 \frac{d\,x_1}{d\,t} + M \frac{d}{d\,t}(y \cos p\,t) = 0$$

$$r_1 x_2 + L_1 \frac{d\,x_2}{d\,t} + M \frac{d}{d\,t}[y \cos(p\,t - 120)\,] = 0$$

$$r_2 y + L_2 \frac{d\,y}{d\,t} + M \frac{d}{d\,t}[x_1 \cos(p\,t - 30°) + x_2 \cos(p\,t - 90°)\,] = 0$$

If these equations are treated by the method already outlined the resulting differential equation is:

$$\sigma D^3 + (k_1 + k_2 + \sigma k_1) D^2 + (k_1^2 + 2 k_1 k_2 + \sigma p^2) D + k_2 (k_1^2 + p^2) = 0$$

In this case $\sigma = 1 - 3/2 \frac{M^2}{L_1 L_2}$

Again the equation obtained by the vector method and the differential equation are identical.

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The Multiple Plant Method for the Equitable Apportionment of Fixed Charges

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Review of the Subject.—*It is the intent of this discussion to present, as simply as possible, a logical and fully reliable method for computing the "fixed charge" portion of commodity rate schedules. The hypothesis that the Service plus Quantity principle in rate-making is widely applicable, even far beyond the field of utility rates, emphasizes the necessity for an equitable basis for the computation of both portions of this dual rate structure. Moreover, since the billings of many customers, if computed strictly according to the cost of service, would be only negligibly affected by their Quantity use, the Service portion of their charge becomes of prime importance.*

The widely-used Peak Responsibility method, while undoubtedly a first approximation to the correct procedure, leads at times to gross inequity. The Eisenmenger method, while technically exact, is tedious in application. The Multiple Plant method, here presented for the first time, is believed to combine the virtues and eliminate the vices of both these methods.

Moreover, since the Service plus Quantity principle was found to control in so remote a field as the freight schedule for car lots of logs, it is entirely possible that the simple and equitable analysis outlined below, may, with proper adaptations, become standard in a wide variety of commodity rate-schedule computations.

ONE of the most intricate of the many perplexing problems which are encountered in the construction of just and reasonable rate schedules is the equitable apportionment of the "fixed" portion of annual operating expense.

This is especially true in cases where energy which is generated in hydroelectric plants is wholesaled to large consumers; because, as Mr. Cravath points in his monograph on Central Station Economics, "The kilowatt-hour output in some cases is immaterial to the owner of the plant, and the sum of the simultaneous demands of the different consumers, at the time of the maximum load on the station, determines the amount of business which can be carried, and the consequent gross revenue."

The *Peak Responsibility Method* for fixed charge apportionment was a logical outgrowth of the fundamental principle just discussed, but was soon found to be only a first approximation to the desired just and reasonable standard. Thus, Eisenmenger in his excellent treatise on Central Station Rates, devotes several pages to proving that the peak responsibility is not the theoretically correct measure for the demand charge of a certain consumer. Following which he covers a score or more of pages with the development of an accurate and adequate method of his own.

The *Eisenmenger method*, as thus outlined and developed, was a distinct advance over the peak responsibility theory, which it may be confidently asserted to have superseded.

However, although the Eisenmenger method is theoretically accurate and satisfactory, its practical application to any given case is complicated and tedious in the extreme. Thus, in order to obtain the proper proportion of the fixed charge for any given consumer, it is necessary to draw no less than seven successively interdependent graphs, two of which are the respective load curves of the consumer and of the system which supplies him. And it is probably because of this unwieldy characteristic that, although Eisenmenger evolved his theory in 1914 and published a series of articles explaining it in 1919, very little is known about it even at the present date. But, in spite of its tediousness, the essential excellence of the Eisenmenger theory makes it a valuable tool for use in rate schedule construction and has led to many attempts to simplify it and to make it more readily workable.

The *Quinan Method*, which was published in the *Electrical World* of June 25, 1921, is one of the latest and most successful of these efforts to attain the same results as the Eisenmenger method but without its attendant complexity. The Quinan method has the same fundamentals as the Multiple Plant method, which will now be presented at some length, but has certain rather important divergences from it which will be detailed later in this discussion.

The Multiple Plant Method. This method of fixed charge apportionment contemplates the division of the total generating capacity into any convenient number of smaller generating plants which at time of peak load are all operating in multiple. These multiple small plants are identical in size, and are assumed to stand idle until the system load requires them to come on. For example, a generating plant capable of supplying a peak of 10,000 kw. is considered as being composed of ten unit plants, each having a generating capacity of 1000 kw. The system load at any hour of the day would be carried by the requisite number of these unit plants operating in multiple; as, for instance, one plant would carry all loads up to and including 1000 kw., two plants in multiple would carry loads above 1000 kw. up to and including 2000 kw., and so on until all ten plants were operating in multiple to carry all loads above 9000 kw. up to and including the full generating capacity of 10,000 kw.

It is assumed for ease of calculation that the entire annual fixed charges against any one of these unit plants will be balanced by a continuing charge of $24.00 per day; from which it follows that, for continuous operation the fixed charge will be $1.00 per plant-hour.

Also, it is readily apparent that, if the unit plant

operates only twelve hours per day, the fixed charge will amount to $2.00 per plant-hour; if only six hours, it will be $4.00; if only four hours, $6.00; and finally, if the unit plant operates only one hour per day, the operating company must obtain $24.00 revenue for that one plant hour of operation.

Consider now a ten-unit multiple plant, six of whose units operate continuously; two operate twelve hours per day; one operates six hours a day, and one operates only during the four hours of a peak which extends from 4:00 p. m. to 8:00 p. m. (See Fig. 1).

The load during any one of these four hours of peak will be carried by ten identical plants operating for the same period of one hour. Each of the first six of these must earn only $1.00 per plant-hour; number seven and number eight must earn $2.00 per plant hour; and numbers nine and ten must earn respectively $4.00 and $6.00 per plant-hour of their operation.

The ten plants during each of the four hours of peak must therefore earn the sum of $6.00 plus $4.00 plus twice $2.00, plus six times $1.00, or a total of $20.00 per hour for all ten. And, since it has been found practically impossible to assign the high cost plant-hours to any specific consumers, this $20.00 total is averaged as $2.00 per plant-hour for each of the ten.

Thus, if consumer "A" uses 4000 kw., and "B" uses 6000 kw. during one of the peak hours, they will pay respectively $8.00 and $12.00, or 40 per cent and 60 per cent of the fixed charge as computed for that hour's use.

It is to be noted at this point, that if all energy use could be condensed into one or more hours of a flat-topped peak, the Peak Responsibility method would give exactly the same results as those obtained by applying the Eisenmenger or the Multiple Plant methods. And further, that precisely because the "peak responsibility" method takes no account of energy use at other hours than those of the peak, it has been necessary to evolve better methods in order to secure an accurate computation of an equitable charge.

To illustrate how the Multiple Plant method takes this into account, consider now the hour between 3:00 p. m. and 4:00 p. m. when nine of the ten plants are operating in multiple. Plants numbers one to six must earn $1.00 per plant-hour, numbers seven and eight must earn $2.00 per plant-hour, and number nine must earn $4.00 per plant-hour; which gives a total for the nine plants of $14.00 per hour, or an average of $1.55 per plant-hour.

At this juncture, it is important to note that if consumers "A" and "B" are not using energy during this hour from 3:00 to 4:00 they will pay no portion of the hourly charge; whereas, under the Peak Responsibility theory, they would still be paying respectively 40 per cent and 60 per cent of the total, while the consumers actually using the energy during that hour, would be getting it for nothing, an injustice which when thus presented is at once obvious.

Continuing the process as above outlined until the *average plant-hour charge* has been obtained for each hour of the twenty-four, the computation of the equitable daily charge of any consumer, whose load curve varies by blocks of a thousand kilowatts per hour, becomes a matter of simple addition.

And although it is unfortunately true that actual load-curves do not vary by any such convenient blocks, yet the method as herein presented will hold true and reliable, regardless of the unit-plant-size and of the time-period which must be chosen to fit any specific load-curve, as will be evident from a study of the tabulations appended hereto.

In fact, as applied to the load curve of a particular large consumer, the customer's proportion of the fixed charges was found by two variations of the Eisenmenger method (*i. e.* the graphic and the arithmetic) to be respectively 39.4 per cent and 39.8 per cent; while, by a careful application of the multiple plant method in which the added refinement of graduated multipliers was introduced, the customer's proportion was found to be 39.6 per cent.

The Weighted Average Demand Factor is the name proposed for the percentage as above obtained. It is defined to be the ratio of the "equivalent demand" kilowatts of the consumer's load curve to the kilowatts of the supplying company's system peak.

The equivalent demand kilowatts of the consumer, as determined by any of the methods already discussed, is thus seen to be a quantity which is different in size from, but identical in application to the customer's kilowatts of demand at time of peak as heretofore used in the peak responsibility method.

The difference between the multiple plant and the Quinan methods lies for the most part in two rather important details. The first of these is that the plant-hour is rigidly adhered to as a unit of measurement and all reference to kilowatt-hours or to "area under the curve" is sedulously avoided. This is because serious error has resulted from the absurdly large quantities which have been obtained for the top multipliers in the triple column of the Quinan method when these precautions were not observed.

A second point of difference is that all variations within an hour's time—if an hour is the unit of time selected—are smoothed down to the average value for that hour.

A third point that is worthy of consideration is the discovery that graduated multipliers should be used, and that these should be interpolated from a curve whose maximum is that resulting from only one hour's use of the topmost plant.

The tabulation which follows shows the close agreement of the values obtained by either method when both are used with proper precautions. It does not, however, show the certainty with which the rigid application of the multiple plant theory as outlined herein precludes the errors so easily possible with the other. But, if proof of this ease of error is desired, a

study of the amazing results sometimes obtained by analyzing almost any pair of load-curves selected at random, will soon make it apparent. This tabulation gives the values of the weighted average demand factor obtained for the pair of load-curves supplied by Mr. Quinan by these two methods, and also by the Eisenmenger graphic method. Another method not herein discussed at length is the very interesting Eisenmenger arithmetic method which dispenses with the use of any curves whatsoever.

Weighted Average Demand Factor—Quinan Curves

Eisenmenger (graphic)	17 per cent
Multiple Plant (tabular)	17.2 per cent
Quinan (tabular)	17.6 per cent

Having thus outlined the general procedure, it remains only to supply an example of its application to a specific case, and the following example is therefore supplied. The analysis as hereinafter shown, for an actual distribution area referred to as Subdivision S, is of interest on at least two counts. For the first, it is given as actually used in a recent important proceeding, and for the second, the very small percentage value involved would have put it out of the accurate range of the ordinary Eisenmenger graphic method. It would not, however, have put it out of accurate range of the Eisenmenger arithmetic method concerning which a later notation will be made.

Subdivision S, Weighted Average Demand Factor

In the following Table I, the quantities in the column

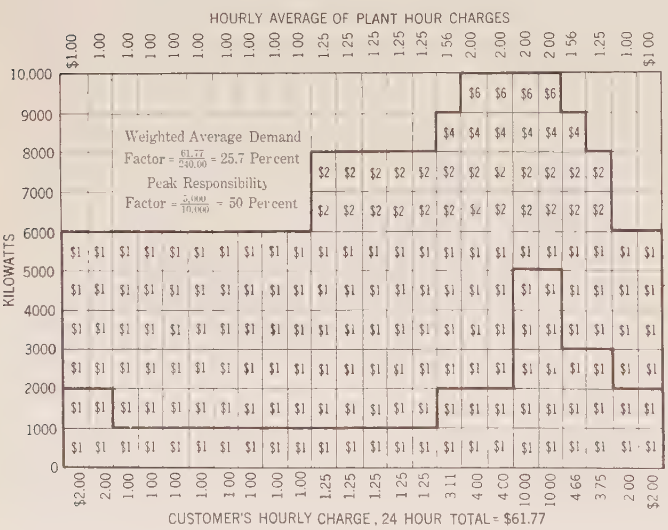

Fig. 1—Apportionment of Fixed Charges by the Multiple Plant Method

headed Subdivision S Kilowatts are mean values as computed from a graphic wattmeter record for a fifteen-day period in the current year. The quantities in the column headed System Kilowatts are similar mean values for the parent system which supplies the electric energy to Subdivision S.

The quantities under Equivalent Demand Multiplier are interpolated from those listed in the last column of Table II, the latter showing the method for the development of the Graduated Multipliers previously mentioned herein.

It will be noted that 199 kilowatts is obtained as the equivalent demand kilowatts of Subdivision S, and that

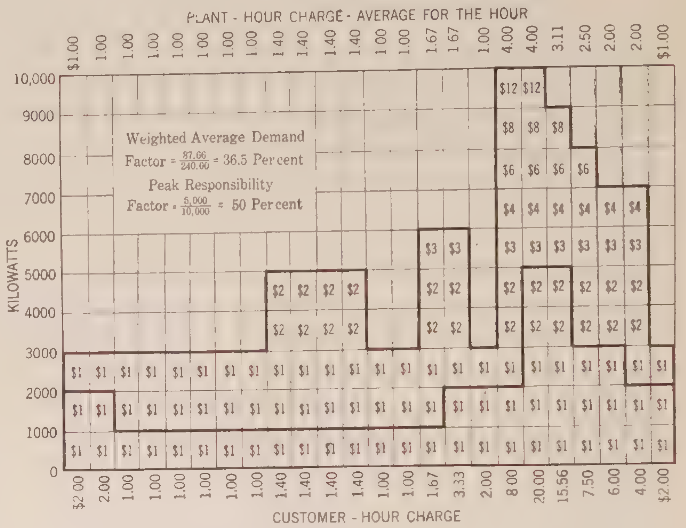

Fig. 2—Apportionment of Fixed Charges by the Multiple Plant Method

the weighted average demand factor, obtained by dividing this 199 by 18,310, the latter being the parent system peak in kilowatts, is 1.09 per cent.

As the similar value, obtained by the Eisenmenger arithmetic method, was found to be 1.17 per cent, a mean value of 1.13 per cent was that actually used in the resulting financial computations.

Contained in Figs. 1 and 2 will be found a graphic comparison and analysis of the widely differing factors obtained by the peak responsibility and the multiple plant methods for the same type of consumer load on two different supply systems. It is especially important to note that the peak responsibility factor would be the same in both cases, in spite of the enormously greater quantity of energy supplied to the rest of the system as shown in Fig. 1.

If further evidence is desired proving that the peak responsibility method is no longer the correct one for use in the equitable apportionment of fixed charges and of the fixed portion of operating expense, the reader is referred to the excellent and conclusive treatment as contained in Eisenmenger's treatise on Central Station Rates.

In conclusion, acknowledgment is made to Messrs. Geo. E. Quinan of the Puget Sound Power & Light Co., Seattle, and D. F. McCurrach, consulting engineer of Portland, Ore., for much data and helpful discussion. The arithmetic variation of the Eisenmenger method

TABLE I

SUBDIVISION "S"

EQUIVALENT DEMAND KILOWATTS AND WEIGHTED AVERAGE DEMAND FACTOR

	System Kilowatts	Demand Multiplier	Subdivision "S" Kilowatts	Subdivision "S" Equivalent Demand Kilowatts
12 Midnight	11,040	1.01	102	103
1 a. m.	10,400	1.00	95	95
2 a. m.	10,480	1.00	91	91
3 a. m.	10,230	1.00	90	90
4 a. m.	10,200	1.00	90	90
5 a. m.	10,560	1.00	93	93
6 a. m.	11,000	1.01	113	114
7 a. m.	13,490	1.08	147	159
8 a. m.	14,090	1.10	232	255
9 a. m.	15,060	1.14	238	272
10 a. m.	15,410	1.16	240	278
11 a. m.	15,550	1.16	247	286
12 Noon	15,560	1.16	167	194
1 p. m.	17,350	1.34	184	246
2 p. m.	17,490	1.37	215	294
3 p. m.	17,330	1.34	215	288
4 p. m.	17,190	1.33	217	288
5 p. m.	16,750	1.28	192	246
6 p. m.	18,010	1.67	198	331
7 p. m.	18,310 peak	1.93	219	423
8 p. m.	17,610	1.39	207	288
9 p. m.	16,570	1.26	185	233
10 p. m.	14,800	1.13	151	170
11 p. m.	12,620	1.05	119	125
	347,100		4,047	4,764
Equivalent Demand Kilowatts........................				199
Weighted Av. Demand Factor (Mult. Plant) 199 ÷ 18,310....................................				1.09 per cent
Weighted Av. Demand Factor (Eisenmenger Arith.)....				1.17 per cent
Mean Value..............................				1.13 per cent

TABLE II

DEVELOPMENT OF GRADUATED MULTIPLIERS

Kilowatts: Group range	Kilowatts: Mid-block value	Number of hours (H)	Mid-block multiplier 24 ÷ H	Cumulative sum of multipliers S	Average multiplier S ÷ no. of plants
18,000—19,000	18,500	2	12.00	36.71	1.93
17,000—18,000	17,500	7	3.43	24.71	1.37
16,000—17,000	16,500	9	2.67	21.28	1.25
15,000—16,000	15,500	13	1.84	18.61	1.16
14,000—15,000	14,500	15	1.60	16.77	1.12
13,000—14,000	13,500	16	1.50	15.17	1.08
12,000—13,000	12,500	17	1.41	13.67	1.05
11,000—12,000	11,500	19	1.26	12.26	1.02
10,000—11,000	10,500	24	1.00	11.00	1.00

was developed by Mr. McCurrach and the writer, working independently, during the early months of the current year; but it is entirely possible that many other engineers have previously discovered and used it in preference to the graphic Eisenmenger method.

A new company has acquired the rights of the Osram patent (German) for Norway. Existing plants have been modernized so that they are now capable of producing 5,000 lamps daily, which is sufficient to supply the Norwegian trade. The factory is under the supervision of workers brought from Germany and the lamps are said to be exact replicas of the German product.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

THE COST OF DAYLIGHT

M. LUCKIESH AND L. L. HOLLADAY

Laboratory of Applied Science, National Lamp Works of G. E. Co.

The remark is often heard to the effect that daylight costs nothing. This is true outdoors, but obviously it costs considerably to enjoy daylight indoors. One of the writers has discussed this subject elsewhere* quite a number of years ago, with the hope that architects would give attention to this aspect of natural lighting. Inasmuch as no data on the subject have appeared, the writers undertook the task of computing the costs of natural lighting as at present practised and to compare these costs with those of adequate electric lighting.

The initial net cost of equipment for natural lighting includes the difference in the cost of the building with and without windows and skylights, the cost of ground area occupied by light-courts, and the cost of extra heating system to supply the difference in heat losses from windows and skylights and from the wall replaced by the glass areas. The annual cost of natural lighting includes interest on the initial net cost, depreciation, cost of repairs, washing and extra fuel. Wall space occupied by windows has not been charged to natural lighting although this is an appreciable item in many cases. The cost of artificial lighting used in the daytime to reinforce daylight has not been charged to natural lighting in making the cost estimates. Deterioration of interiors due to natural lighting and various items of minor importance have been omitted. In fact computations were confined to the major factors which are quite tangible.

In the accompanying table the cost of natural lighting is compared in each of nine representative cases with the cost of electric lighting. The initial cost of equipment for electric lighting consists of the cost of wiring, fixtures, and portables, and its annual cost consists of interest upon the initial investment, depreciation, repairs, lamp renewals, and electric energy. Adequate and proper artificial lighting was assumed in all cases excepting the first dwelling. In fact, the electric lighting provided in all these cases is above the present average and in most cases considerably above. Owing to this and to the exclusion from daylight costs of a number of items which could justly be charged to daylight, the costs presented in the table are more than fair to daylight.

According to the estimates the initial net cost of natural lighting for dwellings is from 110 to 225 per cent of the initial net cost of electric lighting; for apartments and hotels from 100 to 140 per cent; for offices about 160 per cent; and for art galleries from 80 to 180 per

Lighting Journal, Vol. 4, Oct., 1916, p. 229; *Illum. Engr.*, London, Nov., 1916; The Lighting Art, McGraw-Hill, 1917; Artificial Light—Its Influence Upon Civilization, 1920.

Abstract of paper before 1922 Convention, I. E. S.

cent. The annual cost of natural lighting was found for dwellings to be from 95 to 125 per cent of the annual cost of electric lighting; for apartments, hotels, and offices where artificial lighting is freely used during the daytime, from 50 to 100 per cent; and for art galleries about 135 per cent. In general it is seen that the costs of daylight are at least of the same order of magnitude as those of electric lighting. This knowledge should make the consumer more considerate of his artificial lighting bills. In fact, economic considerations indicate that there will be many cases in the future where artificial lighting will supplant natural lighting entirely.

INITIAL AND ANNUAL COSTS OF NATURAL AND OF ELECTRICAL LIGHTING

Description	Initial Cost		Annual Cost	
	Natural	Electric	Natural	Electric
I—Seven-room frame house with hot-water heat and slightly above average present standard of electric lighting equipment	$601	$265	$93	$75
II—Same as I, excepting brick construction	505	265	86	75
III—Seven-room brick house adequate windows and electric lighting equipment	658	610	111	120
IV—Five-room brick apartment, usual windows but adequate electric lighting	225	230	39	65
V—Modern hotel, room and bath	161	115	14	14
VI—A suit of office rooms—				
Without light-court	667	976	86	290
With light-court	1584	976	141	290
VII—Top-lighted paintings gallery, 33 x 115 ft. louvers for controlling daylight; adequate artificial lighting equipment above sub-skylight	8017	4550	...	...
VIII—Top-lighted paintings gallery, 52 x 88 ft. without louvers but with adequate artificial lighting equipment above sub-skylight	3254	4088	577	479
IX—Side-lighted art gallery, 33 x 88 ft. windows on one side and pendant artificial lighting units	3210	1800	308	214

ARCS AT FILAMENT RUPTURE IN GAS FILLED TUNGSTEN LAMPS*

In the course of the life tests conducted on stationary racks, arcs have been found to occur in a small percentage of gas filled tungsten filament lamps subjected to normal burning.

Arcs at Filament Rupture

The accompanying photograph shows one of these arcs. The phenomenon may be attributed to the burning out or breakage of a lamp filament which in failing draws an arc across the hot gap between the ends of the filament at the point of rupture. Even in the smaller sizes of gas filled lamps, these arcs are sometimes as much as 1/2 inch long. They persist for various periods; in one instance one of these arcs in a 75-watt lamp lasted 14 hours.

After the arc has once been quenched due to the shutting off of the current, it is not possible to re-establish it at the usual operating voltage of the lamps. Such arcs of course have no ill effects in service.

*Communicated by Electrical Testing Laboratories.

CAPITAL OF MICHIGAN WILL HAVE FIRST ARCHITECTURALLY UNIFORM LIGHTING SYSTEM

Lansing Adopts Plan Whereby Every Paved Street Will Ultimately Be Lighted From Ornamental, Underground-fed Standards—How the Needs of Each Class of Streets Are to be Met

BY OSCAR E. BULKELEY,

Superintendent, Board of Water and Electric Light Commissioners

Lansing, the capital of Michigan, will be the first city in the United States to have an architecturally uniform system of street lighting units. A comprehensive scheme which will provide eventually for the illumination of every paved street by ornamental, underground-fed standards has been adopted, and the first 350 units are now being installed. The lighting plan was formulated by the writer in consultation with illuminating engineers of the General Electric Company, and was an outgrowth of a general feeling of dissatisfaction with the existing boulevard lighting system which is not only poorly designed but inefficient. It was realized that the time was opportune for a change, while the investment in existing lighting was still comparatively small, involving no great loss by replacement, and before making a substantial additional investment for extending the system, especially since the contemplated extensions included the most important thoroughfares in the city.

The scheme adopted divides the illumination into five classes according to types of streets and their lighting requirements, as follows:—

The principal business streets.
The secondary business streets.
The main boulevards and thoroughfares.
The secondary residential streets.
The parks, plazas and other open places.

The standards and lighting units on all streets will be of the same architectural family and will harmonize in design with one another and with their surroundings. Thus the distressing variance in types that is so often noticeable where a city's lighting equipment has been acquired piecemeal will be absent in Lansing. On the contrary, a novel and very pleasing uniformity in appearance will characterize it.

This installation will be the first in which the design, known by some as the Saratoga Unit, will be produced in alabaster rippled glass, this pattern having heretofore been restricted to globes having a diffusing surface. This will give an added element of distinctiveness to Lansing's new system.

Intensive lighting will be used in the main business sections of Washington and Michigan avenues. In these sections, standards 20 feet from ground to light source, carrying two form 12 Novalux units with

medium alabaster rippled globes and canopies, each equipped with a 10,000-lumen (1000 candle-power), 20 ampere series Mazda lamp are proposed. In the bases of the standards will be installed Type I. L. transformers taps that will permit the future use of 15,000-lumen (1500 c. p.) lamps. This transformer raises the 6.6 ampere line current to 20 amperes. Not only will this provide for the use of the more efficient high-current lamp, but it will effectively insulate the pole from the high voltage of the underground circuit and protect the lamp from line surges.

The standards are to be spaced from 110 to 135 feet apart and opposite each other. At present the business district is inadequately lighted by obsolete cluster type standards, although there are now nearly double the number of standards contemplated in the new lighting system.

Similar units to those just described will be installed along secondary business streets, with the difference that only one unit to a standard will be used. The standards will be approximately 15 feet from the ground to the light source. On the more important secondary streets and on the principal streets beyond the two-light standards, 10,000-lumen (1000 c. p.) lamps are planned. In other locations, 6000-lumen lamps, with provisions for the use later of 10,000-lumen lamps, will be used.

The spacing of the units on these secondary streets will vary with the width and importance of the street. On the narrow ones, the standards will be staggered, with one to each 55 to 75 feet of street. On wide streets the standards will be placed opposite, at intervals of from 100 to 125 feet.

The main boulevards and thoroughfares are the principal routes for incoming and outgoing traffic, and hence demand lighting that will make it possible to drive an automobile through them at a moderate speed without the use of bright headlights. In these installations 4000-lumen (400 c. p.) Mazda lamps in a Form 8 Novalux, polycase glassware will be used, mounted on a King Manufacturing Company's French design standard providing for a height of 13 feet to the light source. The spacing will be approximately 100 feet at street intersections, increasing to a maximum of 140 feet.

Pennsylvania Avenue is an example of a broad boulevard having a beautiful grass parkway in the center, ornamented with shrubs and flower designs, on either side of which is a paved driveway. There will be a single row of the boulevard type standards placed on the center line of this parkway. There is, however, a section of this boulevard south of Main Street where trolley tracks will be placed in the central parking. There, the lighting standards will be installed along the sidewalk curb for the reason that if the units were mounted on the double bracket trolley poles in the parking, there would be an objectionable shadow on the street side of the trolley cars, especially when a car stopped to discharge or take on passengers.

The *I L* transformer used with these standards will have a tap which will permit the use of a 6000-lumen (600 c. p.) lamp when increased traffic in certain locations necessitates such a change.

For the secondary residential streets the same standard as that to be used for the boulevard lighting, except that it will be a little shorter, will be employed. It will be equipped with the same lighting unit and a 2500-lumen (250 c. p.) Mazda lamp. The standards will be installed at intervals of from 100 to 150 feet of street.

The main park drives will be equipped with lighting of the boulevard type, and minor roads and walks with standards like those used in the residential districts. Plazas, playgrounds, etc., will be considered from the standpoint of their individual needs and requirements and will be lighted accordingly.

The details of this entire plan have been approved, although its realization in the business district will require the active cooperation of the business men.

When the installation is complete, Lansing will have more than a modern and highly efficient lighting system. On account of the uniformity of the types of standards and lighting units selected, the general appearance of the city will be greatly enhanced. Clearly it will be a progressive step toward the "city beautiful" and will harmonize completely with the city plan which was recently developed for Lansing. Furthermore, the plan is elastic in that it provides for the use of more powerful lamps as the future needs of the city may require.

The above briefly outlines the adopted plans for the future lighting of the streets of Lansing. The installation on Pennsylvania Avenue has been completed and is shown in the accompanying illustration. Groups of ten standards each are connected to individual 2.4 kw. type S. L. transformers which are fed by existing series street lighting circuits.

A single conductor No. 8 B & S boulevard lighting cable for 600 volts service is used. The cable has a 1/16 in. varnished cambric insulation surrounded by a lead sheath of 1/16 in. thickness, which in turn is covered with 100 pound jute yarn not less than 5/64 in. thick, thoroughly impregnated with a hot asphaltum compound. Every length of cable was tested for five minutes on an alternating electromotive force of 3000 volts and a fifteen foot sample of each length was subjected to a test of 6000 volts. This is the specification for what is known as 1250 volt cable.

Upon the installation of 87 of the 13 foot standards, equipped with 400 candle-power lamps, the cost for labor was $28.60, material $81.00, a total of $109.60 per standard. This includes the standard, lighting unit, underground cable, S. L. transformer and their installation, but does not include any charge for the existing series circuits to which the S. L. transformers are connected or the constant current transformers at the station. The above is considered a moderate cost for so excellent an installation.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

A. I. E. E. Spring Convention

PITTSBURGH, PA., APRIL 24-26

A royal welcome and fine program will be given the visiting members of the American Institute of Electrical Engineers at the national convention to be held in Pittsburgh, April 24-26. The local convention committee has been very active, and in cooperation with the Meetings and Papers Committee, has arranged a technical program which should prove attractive to all engineers, aside from the opportunities offered for visits to engineering works in the Pittsburgh industrial district.

The keynote of the convention in its technical program will be the operation, control and protection of transmission and distribution systems. The practises and operating experiences on such systems as those of the Public Service Company of New Jersey, The Philadelphia Electric Company and the Duquesne Light Company will be presented at the meeting and in addition, papers by specialists will discuss the fundamentals of the problems. The protective devices committee has assembled and digested a great amount of field data which will appear in the papers presented at the meeting.

Other features of the program will be papers devoted to electric furnaces, illumination, reactors, locomotive performance and electric heating, and the papers should prove interesting to a large group of operating engineers and also to stimulate good discussions. The April convention has a program largely presented by operating men on current problems and practises in the central station and industrial fields and should afford the profession some very valuable data and discussion.

One of the features of the convention will be the visit through the works of the Westinghouse Company. The visitors will go through all departments in small groups and also inspect the broadcasting station KDKA and its studio. After the plant inspection there will be a banquet and cabaret entertainment furnished by the manufacturing company. In the laboratories special arrangements have been made to demonstrate the testing of lightning arresters; an interesting feature of these tests will be the application of the oscillograph to the high-voltage discharges.

Headquarters during the convention will be at the William Penn Hotel, where, in addition to the meetings, arrangements have been made for buffet lunches and a banquet which will be held at 6:30 on the evening of Wednesday the 25th. Speakers of national prominence will talk on national topics of vital significance to the electrical industry and the engineering profession, so that the banquet should prove an unusually strong drawing card.

Since the Pittsburgh district abounds in great manufacturing establishments, arrangements have been made to visit these works on Friday the 27th. Steel mills, coal mines, glass works, insulator works and other industries will be inspected and in addition, the Duquesne Light Company and the West Penn Company invite the members to visit the power houses and transmission line installations in their respective territories. H. J. Heinz also invites the members to inspect the source of the celebrated 57 varieties.

The program is as follows:

PROGRAM

TUESDAY MORNING, APRIL 24

Registration and Committee Meetings.

TUESDAY AFTERNOON

TECHNICAL SESSION

1. *Economical Value of Resistance in the Grounded Neutral*, by H. H. Dewey, Assoc. A. I. E. E., Power & Mining Engineering Dept., General Electric Co.
2. *The Neutral Grounding Reactor*, by W. W. Lewis, Member A. I. E. E., Power & Mining Engineering Dept., General Electric Co.
3. *Operating Performance of a Petersen Coil*, by J. M. Oliver, Assoc. A. I. E. E., Operating Engineer, Alabama Power Co., and W. W. Eberhardt, Assoc. A. I. E. E., Electrical Engineer, Alabama Power Co.
4. *Present Day Practises in Grounding of Transmission Systems*—Committee Report.
   I. *Systems Transmitting at Generated Voltage*, by W. W. Woodruff, Assoc. A. I. E. E., Philadelphia Electric Co.
   II. *Systems Transmitting at Higher than Generated Voltage*, by E. C. Stone, Member A. I. E. E., Duquesne Light Co.

TUESDAY EVENING

TECHNICAL SESSION

5. *Third Class Conductors and Mechanism of Arcing Ground*, by C. P. Steinmetz, Fellow A. I. E. E., Chief Consulting Engineer, General Electric Co.
6. *Surges on Transmission Lines*, by J. Slepian, Assoc. A. I. E. E., Research Engineer, Westinghouse E. & M. Co., and J. F. Peters, Member A. I. E. E., Electrical Engineer, Westinghouse E. & M. Co.

WEDNESDAY MORNING, APRIL 25

TECHNICAL SESSION

7. *Some Fuel Determinations on the Southern Pacific System*, by A. H. Babcock, Fellow A. I. E. E., Electrical Engineer, Southern Pacific Railroad.

8. *Some Problems in Electric Furnace Operation*, by F. V. Andreae, Assoc. A. I. E. E., Electrical Engineer, Anniston, Alabama.
9. *A New Electric Furnace*, by A. N. Anderson, Vanadium Steel Corp., and B. D. Saklatwalla, Vanadium Steel Corp.
10. *Heating a Cotton Weave Shed by Electricity*, by C. T. Guildford, Member A. I. E. E., Westinghouse Electric & Mfg. Co.
11. *New Applications of Electric Furnaces*, by Frank Hodson, President, Electric Furnace Construction Co.

WEDNESDAY AFTERNOON

TECHNICAL SESSION

12. *Relay System of Duquesne Light Co.*, by H. P. Sleeper, Assoc. A. I. E. E., Duquesne Light Co., Pittsburgh, Pa.
13. *Ground Selector Relay Scheme*, by P. Ackerman, Assoc. A. I. E. E., Shawinigan Water & Power Co., Montreal, Can.
14. *The Distance Relay for Automatically Sectionalizing Electrical Networks*, by L. N. Crichton, Member A. I. E. E., Westinghouse Electric & Mfg. Co.
15. *Lighting and Control Equipment for the Eastman Theater*, by F. A. Mott, Member A. I. E. E., Electrical Engineer, Wheeler-Green Electric Co., Rochester, N. Y., and L. A. Jones.

WEDNESDAY EVENING

Banquet at William Penn Hotel.

THURSDAY MORNING, APRIL 26

TECHNICAL SESSION

16. *Survey of Lightning Disturbances on a Distribution System*, by M. MacLaren, Assoc. A. I. E. E., Professor of Electrical Engineering, Princeton University.
17. *Experiences with Reactors*, by N. L. Pollard, Fellow A. I. E. E., Consulting Engineer, Public Service Electric Co., Newark, N. J.
18. *Short-Circuit Forces on Reactor Supports*, by R. E. Doherty, Assoc. A. I. E. E., Designing Engineer, General Electric Co., and F. H. Kierstead, Assoc. A. I. E. E., Engineer, General Electric Company.
19. *Proposed Insulator Tests and Specifications*, by the Working Committee on Insulators of the Standards Committee, P. Junkersfeld, Chairman.

THURSDAY AFTERNOON AND EVENING

Visit to plant of Westinghouse Electric & Mfg. Co. and dinner at East Pittsburgh.

FRIDAY, APRIL 27

Visits to points of interest in the Pittsburgh district such as power plants, substations, steel mills, glass works, machine shops and universities, and insulator factories, pickle factory and a coal mine.

The Annual Convention

COMMITTEES REPORT EXCELLENT PROGRESS IN PLANS FOR SWAMPSCOTT MEETING

A tentative outline of the June Convention, which will be held at Swampscott, Mass., June 25-29, 1923, was made by the Meetings and Papers Committee at its meeting in New York on Friday, March 23, 1923.

Monday morning and afternoon will be devoted to the meeting of the Section delegates, and in the evening there will be an informal reception and dancing for the delegates.

On Tuesday morning President Jewett will give his annual address, after which a leading educator will give an address on "Trend in Education Systems." In the afternoon on Tuesday there will be inspection trips, golf and tennis for the visitors. In the evening will be held the President's reception, followed by a dance.

Wednesday morning and afternoon will be devoted to technical sessions. In the evening a beach party is planned for the entertainment of the guests, followed by an informal dance.

On Thursday morning another technical session will be held, and in the afternoon there will be a meeting of the Board of Directors and a meeting which will consist of reports of the Technical Committee Chairman, after which golf, tennis and trips will be arranged. In the evening Capt. Belknap will give an illustrated lecture on the "North Sea Mine Barrage."

On Friday morning another technical session will be held and in the afternoon arrangements have been made for some interesting inspection trips, tennis, golf, baseball and other sports. In the evening there will be informal dancing.

One of the keynote sessions of the meeting will be devoted to the practises and trend in steam power stations. Other topics of major importance will be those concerning cable dielectrics, use of thermo indicators in transformers, street lighting, and communication.

At this Convention it is expected that a large attendance of college professors will be had, because the annual meeting of the Society for the Promotion of Engineering Education occurs a few days previously at Ithaca, N. Y.

The committee is attempting to get a great deal of diversity in the program and the arrangements for visits and facilities for golf and tennis are excellent, so that the afternoons can be largely devoted to sports and social affairs.

A. I. E. E. Directors Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, March 16, 1923.

There were present: President Frank B. Jewett, New York; Vice-President W. I. Slichter, New York; Managers E. B. Craft, L. F. Morehouse, New York, F. F. Fowle, Chicago, H. M. Hobart, Schenectady, G. L. Knight, Brooklyn, H. W. Smith, Worcester, R. B. Williamson, Milwaukee; Secretary F. L. Hutchinson, New York.

Approval by the Finance Committee of monthly bills amounting to $21,287.76 was ratified.

A request for financial cooperation in the publication of International Critical Tables, under the auspices of the International Research Council, was presented. Information was presented showing it to be a valuable publication, toward which other technical and scientific organizations of the country are contributing; and upon the recommendation of the Finance Committee, it was voted that an appropriation of $100 be made toward this year's publication of the Critical Tables.

A report of the meeting of the Board of Examiners held March 12 was presented; and the actions taken at that meeting were approved. Upon recommendation of the Board of Examiners the following action was taken upon pending applications: 161 Students were ordered enrolled; 278 applicants were elected to the grade of Associate; 11 applicants were elected to the grade of Member; 12 applicants were transferred to the grade of Member; 4 applicants were transferred to the grade of Fellow.

Upon recommendation of the Committee of Award of Institute Prizes, the Board modified the conditions of award in order to provide for the automatic placing in competition for the Transmission Prize, of all eligible papers presented before the Institute during the year, without the necessity of the authors specifically placing their papers in competition; this change in procedure to commence with the year 1922.

The report of the Tellers Committee of its canvass of the nomination ballots received for the Institute offices to be filled at the coming annual election, was presented; and the Board selected the "Directors' Nominees," as listed elsewhere in this issue.

Reference to other matters discussed may be found in this and future issues of the JOURNAL under suitable headings.

RESOLUTIONS REGARDING INDICTMENT OF SEVEN MEN ASSOCIATED WITH THE EMERGENCY CONSTRUCTION COMMITTEE OF THE COUNCIL OF NATIONAL DEFENSE

The following resolutions were adopted unanimously by the Board of Directors of the American Institute of Electrical Engineers at its meeting held March 16, 1923:

WHEREAS, the Board of Directors of the American Institute of Electrical Engineers has learned through the public press of the indictment of professional engineers of high standing for alleged acts in connection with their work and efforts, which are presumed to have been in aid of their country in the great world war, therefore be it

"RESOLVED: That the Board urge that the charges be tried at the earliest possible moment in order that the guilty may be punished and the innocent be freed of the serious accusations which have been made against these men; and be it further

"RESOLVED: That copies of these resolutions be sent to the President and the Attorney General of the United States, and printed in the JOURNAL of the Institute."

A. I. E. E. Annual Election

At the meeting of the Board of Directors of the Institute held in New York, March 16, the report of the Committee of Tellers, giving the result of its canvass of the nomination ballots received for the offices to be filled at the coming annual election, was presented.

This report included the names of all candidates eligible for election, the names of those who received less than three per cent of the total nomination vote having been eliminated, in accordance with the requirements of the constitution.

The Board selected, by ballot, the following ticket of "Directors' Nominees" for the respective offices, in accordance with the provisions of the constitution.

For President:	Harris J. Ryan, Stanford University, Calif.
For Vice-Presidents:	District No. 2 (Middle Eastern)
	William F. James, Philadelphia, Pa.
	District No. 4 (Southern)
	H. E. Bussey, Atlanta, Ga.
	District No. 6 (North Central)
	Herbert S. Sands, Denver, Colo.
	District No. 8 (Pacific)
	J. E. Macdonald, Los Angeles, Calif.
	District No. 10 (Canada)
	S. E. M. Henderson, Toronto, Ont.
For Managers:	H. P. Charlesworth, New York, N. Y.
	William M. McConahey, Pittsburgh, Pa.
	W. K. Vanderpoel, Newark, N. J.
For Treasurer:	George A. Hamilton, Elizabeth, N. J.

The election ballots were mailed to the entire membership prior to April 1, in accordance with the constitution.

The report of the Committee of Tellers follows:

REPORT OF COMMITTEE OF TELLERS ON NOMINATION BALLOTS

March 6, 1923

To the Board of Directors,
American Institute of Electrical Engineers

Gentlemen:

This Committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots received for officers of the Institute for 1923-1924. The result is as follows:

Total number of envelopes said to contain ballots, received from the Secretary		1989
Rejected on account of bearing no identifying name on outer envelope	41	
Rejected on account of having reached Secretary's office after February 28	48	
Envelopes received containing no ballots	3	92
Leaving as valid ballots		1897

These valid ballots were counted and the result is shown below:

FOR PRESIDENT

Harris J. Ryan	1793
Scattering and blank	104
Total	1897

(The scattering vote was divided among 29 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices).

FOR VICE-PRESIDENTS

District		
No. 2. Middle Eastern		
	Wm. F. James	1514
	Scattering and blank	383
No. 4. Southern		
	H. E. Bussey	1417
	Scattering and blank	480
No. 6. North Central		
	H. S. Sands	1500
	F. W. Springer	65
	Scattering and blank	332
No. 8. Pacific		
	J. E. Macdonald	1523
	Robert Sibley	66
	Scattering and blank	308
No. 10. Canada		
	S. E. M. Henderson	1518
	Scattering and blank	379

(The scattering vote was divided among 46 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices).

FOR MANAGERS

Wm. M. McConahey	1527
W. K. Vanderpoel	1509
H. P. Charlesworth	460
Scattering and blank	2195
Total	5691

(The scattering vote was divided among 272 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices).

FOR TREASURER

G. A. Hamilton	1545
Scattering and blank	352
Total	1897

(The scattering vote was divided among 8 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices).

Respectfully submitted,
NORMAN T. KOHLHAAS, *Chairman*
E. W. LOOMIS
J. W. NOSTRAND
E. R. DE CASTILLO
LAWRANCE E. FROST
Committee of Tellers

A. I. E. E. Year Book

The A. I. E. E. 1923 Year Book is available to members without charge, upon application to the secretary, 33 West 39th Street, New York, N. Y.

The book contains an alphabetical and geographical catalog of the membership, revised to January 1, 1923; also the constitution, by-laws, lists of officers and committees, and much additional information relating to the activities of the Institute.

Revision of A. I. E. E. Standards

The Standards Committee of the A. I. E. E. has undertaken a thorough revision of the A. I. E. E. Standards. The work of revision is being carried out on the basis of certain principles as follows:

1. The Standards will be subdivided into separate sections, each adequate to the needs of the machinery with which it deals.

2. There will be sections relating to general principles, technic of measurements, etc. such as:

General Principles upon which Temperature Limits are Based.

Standards for the Measurement of Test Voltages in Dielectric Strength Tests.

Standard Definitions and Symbols.

3. Whenever practicable the same general order of arrangement of the contents will be followed in each of the sections. This order of arrangement is as follows:

Scope
Service conditions
Definitions
Rating
Temperature limits
Other limits to rating
Efficiency
Dielectric strength and insulation resistance
Regulation
Variations in voltage, speed and frequency
Construction details, etc.

Twenty-seven sections with the following titles are being prepared. (This division and the titles are not necessarily final and may be subject to modifications).

Designating number	Title
1	General Principles upon which Temperature Limits are Based.
2	Standard Definitions and Symbols.
3	Standards for the Measurement of Test Voltages in Dielectric Strength Tests.
4	Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General.
5	Standards for Alternating-Current Synchronous Generators and Motors and Synchronous Machines in General.
6	Standards for Synchronous Converters.
7	Standards for Induction Motors and Asynchronous Machines in General.
8	Standards for Alternating-Current and Direct-Current Fractional Horse Power Motors.
9	Standards for Railway Motors.
10	Standards for Prime Movers and Generator Units.
11	Standards for Power and Distributing Transformers.
12	Standards for Induction Regulators.
13	Standards for Instrument Transformers.
14	Standards for Control Apparatus.
15	Standards for Oil Circuit Breakers.
16	Standards for Air Circuit Breakers, Lever Switches, Enclosed Lever Switches and Disconnecting Switches.
17	Standards for Bus Bar Supports, Ammeter Jacks, Potential Plugs, Test Plugs, Power Fuses and Potential Transformer Fuses.
18	Standards for Switchboard Panels.
19	Standards for Lightning Arresters.
20	Standards for Electric Railways.
21	Standards for Wires and Cables.
22	Standards for Transmission Lines and Distribution Lines.
23	Standards for Meters and Instruments.
24	Standards for Telegraphy and Telephony.
25	Standards for Radio Communication.
26	Standards for Storage Batteries.
27	Standards for Illumination.

It is the intention of the Committee to concentrate on a few sections which, when completed, will serve as models for the others. These are:

3. Standards for the Measurement of Test Voltages in Dielectric Strength Tests.

4. Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General.

6. Standards for Synchronous Converters.

8. Standards for Alternating-Current and Direct-Current Fractional Horse Power Motors.

11. Standards for Power and Distributing Transformers.

14. Standards for Control Apparatus.

The work is being carried on informally and suggestions are welcome from all who are interested. Each section will be approved by a representative working committee before being approved by the Standards Committee. It is proposed that before final adoption each section shall be printed or otherwise duplicated. Appropriate notice will then appear in the Journal so that any one interested may obtain copies and contribute criticisms and suggestions.

COOPERATIVE MOVEMENT FOR STANDARDIZATION IN THE ELECTRICAL INDUSTRY

For some time past, there has been a growing feeling in the electrical field that the several electrical associations engaged in standardization work should cooperate in presenting a single set of electrical standards to the A. E. S. C. for approval as American Standards. The lack of generally accepted American standards has been a considerable handicap to this country in connection with international standardization, and has undoubtedly increased the difficulty of selling electrical products abroad.

During the summer of 1922, a movement was started to revise the A. I. E. E. Standards, subdividing them into a number of separate pamphlets or sections, each covering completely the standards for one kind of apparatus. An outline of this work is referred to above.

These two movements—one to revise the A. I. E. E. Standards, and the other to arrive at a single set of American Standards through some cooperative effort—were joined in a resolution adopted by the A. I. E. E. Standards Committee Nov. 10, 1922, and approved by the A. I. E. E. Board of Directors Dec. 8, 1922.

The resolution follows:

The Standards Committee of the A. I. E. E. recognizes the need of a single complete set of American Standards approved by the A. E. S. C., supported by the entire electrical industry, and acceptable to the public.

The Standards Committee is undertaking a revision of its present rules mainly in form.

The Institute desires to contribute these revised Standards as part of the suggested American Standards, and suggests that other organizations, such as the Electric Power Club, the N. E. L. A., the A. M. E. S., and any other organizations interested, may consider this an opportune time to initiate a cooperative effort with this end in view.

To accomplish this result, the following procedure is suggested:

That each organization interested be asked to designate an official representative to act with a representative of the A. I. E. E. These representatives are to present such matter as their societies think should properly be included in the suggested American Standards, and to pass judgment on the resulting compilation. They will also refer the resulting compilation (if in their respective judgments such reference is necessary) to their societies for approval before its submission to the A. E. S. C. for approval as American Standard, according to the procedure which the A. E. S. C. has established.

Thus far standards for certain electrical machinery and apparatus only have reached a stage where the cooperative effort can take tangible form and to deal with these, the N. E. L. A., the E. P. C. the A. M. E. S., and the A. I. E. E. have appointed such official representatives. This Joint Committee has begun work and has had under consideration a section of Standards for Control

Apparatus. It is expected that this first section which is now in the hands of a representative working committee will be ready for circulation to all those interested within a short time.

PRELIMINARY DRAFT OF STANDARDS FOR CONTROL APPARATUS

As announced above, work has been under way for some time on the preparation of standards for Control Apparatus.

It is expected that sufficient progress will have been made so that this section of the proposed revision will be in shape for submission to the Standards Committee for approval as Institute Standards at the meeting of the Committee to be held about May eleventh.

It is expected that copies of the proposed Standards will be available for distribution to all those interested by April 16th. The Standards Committee requests that all interested engineers secure copies by applying to the Secretary of the Institute and give the Committee the benefit of their criticisms and suggestions.

North Eastern District Establishes Prize for Worthy Paper

The Executive Committee of Geographical District No. 1 (North Eastern) held a meeting in Worcester, Mass., on March 14 and approved the following rules of procedure relative to the prize which the committee voted last December should be awarded to the author of the most worthy paper presented at a meeting of any Section in the District during the year:

Rules Governing Competition

1. This prize, established by the Sections in District No. 1 of the American Institute of Electrical Engineers, shall consist of $25 cash, accompanied by a suitable certificate, to be awarded each year to the author (or authors) of the paper which is designated by a duly authorized Committee of Award as the most worthy original paper presented during the Institute year (August 1 to July 31) at a meeting of any Section of District No. 1 by a Fellow, Member, Associate or Enrolled Student of the Institute who resides in District No. 1 and who has never had published in the A. I. E. E. Journal or Transactions a paper presented before the Institute or any of its Sections.

2. In this competition, the Chairman of the Section at which the author's paper is presented, shall by means of a written communication, submit the paper to the District Vice President prior to July 15 of the Institute year in which the paper was presented.

3. A paper by joint authors is eligible for this competition, provided each author qualifies under these rules. A prize awarded a joint paper shall be divided equally between the authors and each author shall be awarded a suitable certificate.

4. The award shall be made by a Committee of Award consisting of three members appointed by the District Vice President. The Committee's interpretation of these rules, its selection of the most worthy original paper and its award of prize shall be final. The Committee may, in its judgment, omit awarding a prize in the event that the quality of the papers submitted is not of a standard that would justify publication in the Journal or Transactions; whereupon the annual prize will be held without further contributions from the Sections, until a satisfactory series of papers has been submitted.

5. The prize shall be presented by the Regional Vice President, or his delegate, at the first fall meeting of the Section at which the paper was presented.

6. The paper shall be published in full or in abstract, in the monthly Journal or annual Transactions of the Institute, or both.

7. Manuscripts shall be submitted in triplicate and shall be typewritten on one side of paper of approximately 8½ by 11 inches.

8. Papers submitted will be judged for (a) originality and subject matter, (b) value as a contribution to electrical knowledge, and (c) expression, technique, and English. The relative weight to be assigned each of these factors shall be determined by the Committee of Award.

Plans for Relief of Coal Situation

In a letter of March 8 from the Executive Secretary of the Federated American Engineering Societies the Institute and its individual members are requested to cooperate in any way possible with the execution of a plan for the relief of the coal shortage particularly as it applies to the domestic situation. John Hays Hammond, Chairman of U. S. Coal Commission, calls attention to a plan devised by a member of the Commission for securing the storage of domestic coal. Under the plan an employee submits to his company, prior to April 1, an estimate of his winter fuel needs. Full payment for the coal to be made by the company at any time delivery is effected, which delivery is at the option of the retail dealer during the six months beginning with April. The company is reimbursed by deducting the cost of the coal from the employee's salary. The deductions, however, are spread in equal installments over the six months period. The employer can thus see to it that the dealer delivers the maximum practicable amount of coal, at the best price and early in the season. Employees, many of whom are accustomed to buy in very small quantities and at maximum prices, make substantial savings and are assured of sufficient coal when needed.

Since engineers are in a position to appreciate keenly the many advantages which will accrue from a better functioning of the coal industry, it would appear that this is an exceptional opportunity to do a public service. It is therefore urged that engineers point out to their clients and employers the advantages of the plan suggested and if such is done it is believed employers will be willing to arrange for the domestic coal purchases of their employees.

Future Section Meetings

Baltimore.—April 20, 1923. Subject: "Insulator Design and Manufacture." Speaker: Mr. K. A. Hawley, Chief Engineer, Locke Insulator Corp.

April 21, 1923. Inspection Trip to the Baltimore Plant of the Locke Insulator Corp., Cromwell & Charles St., Baltimore, Md.

May 18, 1923. Subject: "Lighting of Factories and Office Buildings." Speaker: Mr. Earl A. Anderson, Engineer, National Lamp Works.

Boston.—April 16, 1923. Subject: "The Panama Canal—Operation, Traffic and Future," by Brig. Gen. Chester Harding, U. S. A., Retired, Ex-Governor of the Panama Canal.

May 15, 1923. Annual entertainment. Program to be announced.

Cleveland.—April 19, 1923. Subject: "Manufacture of Copper Wire and Cable." Speaker: Mr. C. F. Hood, Superintendent of the Electric Cable Factory of the American Steel & Wire Co.

May 24, 1923. Annual meeting. Speaker: Dr. Jewett. National President of the A. I. E. E.

Detroit-Ann Arbor.—April 13, 1923. Speaker to be announced.

May 11, 1923. Speaker to be announced.

June, 1923. Annual meeting and election of officers.

Erie.—May 14, 1923. Subject: "Sound," Speaker: Prof. Dayton C. Miller, of the Case School of Applied Science.

Philadelphia.—April 9, 1923. Subject: "Lightning Protection." Speaker: Major Malcolm MacLaren.

May 14, 1923. Subject to be announced. Speaker: Mr. C. J. Russell.

June 11, 1923. Annual meeting, McCall Field, Highland Park, Pa.

Seattle.—April 18, 1923. Subject: "The Columbia Basin Project." Speaker: Mr. Willis T. Batcheller, Consulting Engineer, Seattle, Wash.

May 16, 1923. Subject: "A Typical Installation of a Long Distance Telephone Toll Cable" by members of the Engineering staff of the Pacific Telephone & Telegraph Co.

Toronto.—April 6, 1923. Joint meeting with the Engineering Institute of Canada at Hamilton.

April 20, 1923. Annual business meeting.

Washington.—April 10, 1923. Subject: "Japanese Power Development." Speaker: Mr. Stephen Q. Hayes, of the Westinghouse Electric & Mfg. Co.

Worcester.—April 12, 1923. To be announced.

May 17, 1923. Annual meeting. Subject: To be announced. Speaker: Dr. Jewett, President of the A. I. E. E.

American Engineering Standards Committee

1923 YEAR BOOK OF THE AMERICAN ENGINEERING STANDARDS COMMITTEE OFF THE PRESS

The 1923 Year Book of the A. E. S. C., which has just come off the press, shows that great progress has been made during the last year in standardization projects affecting electrical industries. Of the thirty-five standards thus far approved by the A. E. S. C., the following eleven are of special interest to the electrical industries: National Electrical Code; Electrical Safety Code; Code for Electricity Meters; Automobile Head-lighting Specifications; Code of Lighting Factories, Mills and other Work Places; Safety Code for the Protection of the Heads and Eyes of Industrial Workers; Illuminating Engineering Nomenclature and Photometric Standards; Methods for Battery Assay of Copper; Specifications for Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots and Ingot Bars; Specifications for Lake Copper Wire Bars, Cakes Slabs, Billets, Ingot and Ingot Bars; and Specifications for Soft or Annealed Copper Wire.

The report shows that at the end of the year a total of 121 industrial standardization projects were definitely under way or had been completed and the standards approved. Of the projects which have reached an official status, fifteen have to do with electrical engineering; twenty-three with mechanical engineering; twenty-one with civil engineering and the building trades; three with automotive subjects; twelve with transport; one with ships and their machinery; fifteen with ferrous metals; four with non-ferrous metals; twelve with chemical subjects; two with textiles; four with mining; and nine projects with topics of a miscellaneous or general character.

Two hundred and seventy-five national bodies—technical, industrial and governmental—are now cooperating in the work of the A. E. S. C. through officially accredited representatives, and more than nine hundred individuals are serving on the sectional committees which carry on the actual standardization work, the A. E. S. C. acting only as an administrative body.

The electrical industry is represented on the American Engineering Standards Committee by the American Institute of Electrical Engineers, the Association of Edison Illuminating Companies, the National Electrical Light Association, the American Electric Railway Association, the Electrical Manufacturers Council, the Associated Manufacturers of Electrical Supplies, the Electrical Manufacturers Club, and the Electric Power Club.

One of the most important accomplishments of the year was the development of a plan of cooperation between the Federal Specifications Board—the body which develops the specifications for all government purchases—and the A. E. S. C., by which the specifications of the Board are submitted informally to the A. E. S. C. before definite adoption. Dr. A. S. McAllister, who has been serving as a special liaison officer of the Bureau of Standards, has been designated by the chairman of the Federal Specifications Board as liaison representative in the cooperative work with the A. E. S. C.

ENGINEERS, SCIENTISTS AND EDITORS PLAN TO STANDARDIZE SYMBOLS AND ABBREVIATIONS

A recent conference held in New York City under the auspices of the American Engineering Standards Committee revealed a sentiment among engineers, scientists, government officials, business paper editors and industrial executives, emphatically in favor of the unification of technical and scientific abbreviations and symbols.

It was agreed on all sides that the standardization of abbreviations and symbols would result in inestimable mental economies. The present situation with respect to the use of abbreviations and symbols in engineering, scientific and other technical fields is comparable to a language which has degenerated into a multiplicity of dialects each of which has to be translated for the users of the others. Abbreviations and symbols constitute an ever growing and important part of the language of engineers, scientists, industrial editors and other technical men. The use of one symbol or abbreviation for several different terms and the use of several different symbols or abbreviations for one meaning are, however, at present causing a great deal of confusion, misunderstanding, and, often, serious errors.

The conference was called upon requests from the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, and the Association of Edison Illuminating Companies, to consider abbreviations and symbols, but after some discussion of the subject it was thought desirable to include as a part of the project, the graphical symbols which are used in engineering drawings, diagrams, and the like, for representing instruments and apparatus and components of them.

It was agreed that the cooperation of foreign standardizing bodies should be sought, in the development of the work. The importance of international uniformity in symbols is great on account of the international character of much engineering and scientific work, and the importance of reference books and periodicals in foreign languages.

The work will go forward under a committee organization developed in accordance with the rules and procedure of the American Engineering Standards Committee.

Thirty-six representatives were present from as many organizations, showing the diversity of interests involved in this project.

CLOSER COOPERATION BETWEEN GOVERNMENT AND INDUSTRY IN STANDARDIZATION WORK

Another important step toward the elimination of differences between specifications for government purchases and specifications for similar materials produced for the general commercial market, was taken at the March meeting of the American Engineering Standards Committee, when it was voted to accede to the suggestion of the Federal Specifications Board that the A. E. S. C. submit to the Board for its information, all standards which are being considered by the A. E. S. C. for approval. In cases where standards before the A. E. S. C. prove also of

interest to any government department, the matter of their formal approval as government standards may then be considered by the Federal Specifications Board.

The Federal Board has for some time used the machinery of the American Engineering Standards Committee to bring its specifications into harmony with the best commercial practise, thereby broadening its source of supply and lessening the cost of production. Under this arrangement twenty-two specifications for government purchases have already been submitted to industry for criticism in advance of their adoption by the Federal Specifications Board.

Through the presence of seven departments of the federal government in the membership of the American Engineering Standards Committee the government has participated in the formulation of industrial standards. Now industry has an opportunity to participate, as an advisor, in the formulation of government standards, thus minimizing the possibilities of duplicated effort in the field of standardization.

Following is a list of the federal specifications which have already been submitted for criticism to industry, through the medium of the American Engineering Standards Committee: Hose for Various Purposes (13 Specifications), Wood Screws, Sterilizing Equipment, Numbered Cotton Duck, Phosphor Tin, Silicon Copper, Pig Lead, Creosote Oil, Asbestos Millboard, Insulated Safes and Cabinets, Rubber Bands, Oil Suction and Discharge Hose, Snap Switches, Rigid Conduit, (Enameled), Dry Cells, Rubber Insulated Wires and Cables, Packing and Gaskets, Manila Rope, Coal Tar Pitch for Roofing, Surfacing Materials for Bituminous Built up Roofing, Sheathing Paper and Unimpregnated Rag Roofing Felt, Coal Tar Saturated Rag Felt for Roofing and Waterproofing.

AMERICAN ENGINEERING COUNCIL

REPORT OF PATENTS COMMITTEE

To the Members of the American Institute of Electrical Engineers: The Patents Committee of American Engineering Council is glad to report that the Sterling-Lehlbach Bill for the Reclassification of Governmental Salaries, H. R. 8928, became a law on March 4th, 1923. It raises the salaries of the Primary Examiners to $5000., which will enable the Patent Office to draw a high class of men for its further appointments and ultimately put the Patent Office on a high plane. It equally benefits all other professional and scientific employees of the Government, including, of course, the engineers.

While the bill will not become effective until July, 1924, the Commissioner of Patents writes that the Patent Office can wait, as the Lampert Bill, which became a law in February, 1922, prevented its going to pieces, and, the Reclassification Bill having become a law, it will have an immediate stimulating effect.

The Patent Committee of American Engineering Council wishes to thank the many engineers who responded to its requests for appeals to Congress to enact the bill. Their combined influence was powerful and, with that brought to bear by the Council, its officers and its committee on the Reclassification Bill, and by other organizations and individuals, had much to do with the successful outcome. We believe that the passage of the bill will, through its influence on the Patent Office, be of great benefit to the progress and prosperity of our country.

The large part which the engineers were able to play in this accomplishment fully justifies the formation of the Federated American Engineering Societies and the American Engineering Council, and shows how essential they are to enable the engineers to exert themselves as a class for the public good. Some of the great societies which are members of the Federation could not, under their constitutions, have appointed committees to take part in legislative action, and even if they had power to appoint such committees, no group of isolated committees could be as effective as a single committee representing all the societies of the Federation, and in emergencies where the time available is very short, as during a short session of Congress and particularly during the closing days of a session, it would often be impossible to get any action through a group of committees, while a single committee could act effectively.

Respectfully,

EDWIN J. PRINDLE,
Chairman, Patents Committee
American Engineering Council.

J. PARKE CHANNING,
Secretary, Patents Committee
American Engineering Council.

CHARLES A. TERRY

FRANK N. WATERMAN

Representatives of A. I. E. E. on
Patents Committee of
American Engineering Council.

MEETING OF EXECUTIVE BOARD OF F. A. E. S.

Many problems of prime importance to the nation and to the engineering profession were considered by the Executive Board of the American Engineering Council, governing body of the Federated American Engineering Societies, at its last meeting, which was held on March 23-24 in Cincinnati.

The Board's sessions were held at the Ohio Mechanics Institute, President Mortimer E. Cooley, presiding. On March 22, at 8 p. m., the Committee on Procedure met at the Hotel Gibson.

President Cooley informed the Committee on Procedure at its last meeting in New York City that at least a dozen engineering societies are about ready to join. President Cooley was authorized to appoint a Committee on Increase in Membership, John A. Stevens of Lowell, Mass., Chairman, and a Committee on Transportation to advise the Executive Board at its Cincinnati meeting as to whether or not there are any points in the problems of the transportation of the United States to which the Federation could with propriety and effectiveness give attention, and if so, to submit a plan in its report to the Executive Board.

Max Toltz of St. Paul was chosen chairman of the Transportation Committee. Other members include Con M. Buck, W. H. Hoyt, W. K. Hatt, Dean Perley, F. Walker and J. S. Barelli.

The Committee on Procedure decided that the entire question of immigration was without the purview of the Federation and that a committee could not properly be appointed to study any phase of it.

Acting upon representations from the Associated General Contractors of America, to the effect that the seasonable aspects of the building industry as well as climbing construction costs were problems constituting an alarming situation, the committee adopted a resolution "viewing with approval the proposed cooperative movement to remove or reduce the element of seasonable demand in the construction industry."

Willingness to name a committee to cooperate with some responsible agency that will direct the movement was expressed. President Cooley was authorized to appoint a committee, should he believe it necessary, to cooperate with some authoritative instrumentality such as the American Construction Council or the Associated General Contractors of America.

A "buyers' strike" is inevitable if the present trend of higher prices continues, it was asserted in the statement of the contractors, signed by Managing Director Richard C. Marshall.

The Committee on Procedure decided that the American Engineering Council would aid in any way within its power and means in bringing about uniform safety legislation. The committee declined to take a stand on the ship subsidy bill, which, it was held, did not come within the scope of the Federation's activities.

A communication from W. S. Moody stating that immigration restrictions have so handicapped production that the nation's commercial growth was being hampered was considered by the Committee. Suggesting that machinery be used to relieve the shortage of unskilled labor, Mr. Moody said:

"I offer for your consideration the proposition that the Council make a thorough survey of industry and select several kinds of work now done manually where great numbers of men could be replaced if power driven devices did the work.

"Having selected sufficient fields of such work to release say 500,000 or more hands, I would then have the Council recommend to all industry that they associate for this purpose and contribute the necessary money to enable various suitable engineering organizations to undertake the development of the necessary devices for performing this work.

"The developmental work should be undertaken by the engineering organization in the same intensive way that similar big production problems were taken up during the War, although of course, with greater regard for reasonable economy."

The Committee voted to submit the question of undertaking an intensive study of labor-saving devices, as outlined by Mr. Moody, to the American Society of Mechanical Engineers.

Decision to undertake a nationwide coal storage investigation was reached and general endorsement of the plan for government reorganization submitted to Congress with the approval of President Harding and Cabinet, and continuance of the Committee on Transportation, headed by Max Toltz of St. Paul, were other outstanding features of the meeting.

The personnel of the committee to conduct the coal inquiry, which is to be made unless there is objection from the constituent societies, will be announced later by President Cooley.

"It is a very opportune moment for an engineering body carefully and painstakingly to survey the entire subject of the engineering and economic phases of coal storage," said the statement prepared for the consideration of the Executive Board outlining the proposed scope of the work.

"It is known that both the Coal Commission and the Department of Commerce will look with favor upon such a survey. Each of the agencies is making studies of certain features of the coal industry, but neither agency will be in a position to give sufficient consideration to the engineering and economic phases of coal storage. The work of the three agencies can be and will be so coordinated as to avoid all duplication, confusion and conflict."

The object of the survey is 'to determine the facts relating to the engineering, chemical, and economic factors involved in, and their influence upon coal storage at the mine and by large and by other consumers of coal."

The Coal Commission, it was stated by Executive Secretary L. W. Wallace, was relying upon engineering methods and engineers. The opinion was expressed that the study, to be of the greatest benefit, should be completed not later than November 1.

"Many have contended," continued the statement to the Executive Board, "that a larger practise of storing coal by consumers would materially reduce the intermittent aspect of the coal industry; would result in an ample supply of coal at all times; would even up the demand for transportation facilities; would enable a larger resort to water transportation; would reduce operating and transportation expenses and, therefore, would lead to a reduction in the cost of coal to the consumer.

"No adequate, comprehensive study of the various engineering and economic factors has been made, whereby a definite conclusion relating to the various advantages claimed for coal storage might be drawn. It is thought, therefore, that a careful study of the engineering and economic phases of coal storage would be timely and important and would inevitably be of value to all concerned."

In forming the committee it is believed that each of the following groups should be represented: Coal mining (bituminous and anthracite), the Bureau of Mines, transportation, public utilities, equipment, economist, chemical engineering. It was thought that any other group or groups that may be able to contribute scientific and fundamental information should be included. The committee will develop the plans, direct the investigation, employ the necessary assistance, and prepare and submit the report.

ENGINEERING FOUNDATION

ARCH DAM INVESTIGATION

At a meeting in San Francisco of the recently formed advisory committee of the Engineering Foundation on the investigation of arch dams, preliminary plans were laid for carrying on the work; a number of existing dams from which useful information could be obtained by making measurements were selected and the work of making the measurements was assigned. A statement of the organization and purposes of the committee was published in the *Engineering News-Record*, November 16, 1922, p. 857. The meeting held in San Francisco on February 26 was attended by Professor C. Derleth, Jr., Chairman, F. E. Weymouth, M. M. O'Shaughnessy, D. C. Henny, Wynn Meredith, R. P. McIntosh and Fred A. Noetzli.

Provided sufficient funds are available, the committee proposes to build later one or more small dams for experimental purposes upon which tests can be made to try out various theories and get information that could not be secured by measuring existing dams. Particular attention will be given to deflections and deformations caused by temperature changes as reservoir conditions vary from full to empty.

Decision was made to make complete studies of deflections, stresses, temperature effect, etc., on eight arch and multiple arch dams. Measurements on each of these dams will be under the supervision of a local committee of four engineers and it is expected that the whole investigation will extend over a period of two or three years.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—W. De V. Bealey, 410 Artisans Bldg., Portland, Ore.
2.—G. Byberg, 641 Van Buren St., Milwaukee, Wis.
3.—John Hamilton, 2610 Lawrence St., Butte, Mont.
4.—T. J. Hodge, Dallas Pr. & Light Co., Park & Marilla Sts., Dallas, Texas.
5.—Charles H. Hollenbeck, 7 Virginia Ave., West Orange, N. J.
6.—Young-Tsieh Huang, c/o J. W. Dietz, Western Electric Co., 195 Broadway, New York, N. Y.
7.—Albert H. Keys, Lawton, Okla.
8.—J. M. Quinlan, 269 Beach Walk, Honolulu, T. H.
9.—N. T. Sauerborn, 1206 Grape St., Syracuse, N. Y.
10.—James Wallace, 3951 Denker Ave., Los Angeles, Calif.
11.—Tobias F. Ziegler, Torrington, Wyo.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m .to 6 p. m.

BOOK NOTICES (FEB. 1-28, 1923).

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Construction et Exploitation des Grandes Reseaux de Transport D'Energie Electrique a Tres Haute Tension. Compte-Rendu des Travaux de la Conférence Internationale tenue à Paris du 21 au 26 Novembre 1921. Paris, L'Union des Syndicats de L'Electricité, 1922. 1176 pp., illus., diagrs., 10 x 7 in., cloth. 100 fr.

The reports of this conference are now available in a well-printed volume of nearly twelve hundred pages containing a review of its organization and purpose, a general report of its activities and the text of the sixty-eight reports presented before it. These reports include summaries of the legislation pertaining to high-tension transmission in various countries, descriptions of existing systems and projects, papers upon various topics connected with the current production and transformation, the construction of high-tension lines, and the exploitation, protection and safeguarding of transmission systems. The conference was attended by delegates from twelve countries. The papers and discussions give a wide survey of the present development of high-tension transmission.

Electricity in Agriculture.

By Arthur H. Allen. Lond., & N. Y., Isaac Pitman & Sons, 1922. (Pitman's Technical Primers). 117 pp., illus., tables, 6 x 4 in., cloth. $.85.

A small book indicating briefly the various ways in which electricity can be used by the farmer for light and power purposes and for electroculture, and the methods by which he can avail himself of electricity. The book also calls to the attention of central station managers the possibilities of the farmer as a customer. Written for British farmers, it treats the questions in the light of British conditions.

Jahrbuch der Elektrotechnik. 1920.

By Karl Strecker. München u. Berlin, R. Oldenbourg, 1922. 232 pp., 10 x 7 in., boards. $1.80.

This Jahrbuch fulfills two purposes. It acts as an index to the important articles on electrical engineering which appeared in sixty prominent scientific periodicals, and it also provides convenient summaries of progress in various electrical fields, compiled by competent authorities. The present volume covers the publications of the year 1920. The information is carefully classified and good author and subject indexes are supplied, making the volume useful for reference use.

Les Marees et Leur Utilisation Industrielle.

By E. Fichot. Paris, Gauthier-Villars et Cie., 1923. (Science et Civilization). 254 pp., 8 x 5 in., paper. 9 fr.

The work of a chief hydrographic engineer of the French navy, this volume is a study of the possibility of using the energy of waves, on a large scale, as a source of industrial power. The author describes the action of the heavenly bodies on the waters of the ocean, the undulatory movements of the ocean and the formation and propagation of waves. This study of the theory of waves is followed by an exposition of the projects intended to utilize the waves as a source of power. The book is intended not only for specialists, but also for legislators and others interested in economic problems.

Meaning of Relativity.

By Albert Einstein. Princeton, Princeton University Press, 1923. 123 pp., 7 x 5 in., cloth. $2.00.

This volume presents, in a translation by Professor Edwin Plimpton Adams, four lectures delivered by Dr. Einstein at Princeton University, during May 1921. The first lecture is upon Space and Time in Pre-Relativity Physics; the second upon the "Theory of Special Relativity;" and the remaining two upon the "General Theory of Relativity."

Plastics and Molded Electrical Insulation.

By Emile Hemming. N. Y., Chemical Catalog Co., 1923. 313 pp., illus., 9 x 6 in., cloth. $5.00.

This treatise is divided into two books. Book one, on plastics in general, contains chapters on ceramic products, calcareous cements and artificial stones, glass, casein products, and plastics for road construction. Book two deals with molded electric insulating materials, both organic and inorganic, describing their properties, preparation and molding.

The book is intended for general readers and for specialists. The essential general facts relating to each topic are presented in readable form. Of great value are the extensive summaries of the patent literature of the past twelve years.

Practical Tests for the Electrical Laboratory.

By C. H. Johnson & R. P. Earle. N. Y., D. Van Nostrand Co., 1923. 347 pp., diagrs., 8 x 5 in., cloth. $2.50.

This text aims to cover all branches of work that may be attempted by students of average industrial high-school or trades-school ability. The experiments involve apparatus of direct interest to electrical workers in all industries. The tests are selected to acquaint the student with the use and care of apparatus, and are arranged so that large classes may be taught with modest equipment.

Principle of Relativity with Applications to Physical Science.

By A. N. Whitehead. Cambridge, University Press, 1922. 190 pp., 9 x 6 in., cloth. 10s 6d. (Gift of Macmillan Co., N. Y.)

This book is not an attempt to expound Einstein's theory, but to set forth an alternative theory of relativity and to show the results deducible from the application of the formulas assumed for the gravitational and electro-magnetic fields. Dr. Whitehead believes that our experience requires and exhibits a basis of uniformity, and that in the case of nature this basis exhibits itself as the uniformity of spatio-temporal relations; a conclusion that entirely cuts away the casual heterogeneity of these relations which is the essential of Einstein's later theory. This uniformity is essential to the outlook of the author. He finally arrives at metrical formulas identical with those of Einstein's earlier theory, but with entirely different meanings ascribed to the algebraic symbols.

Principles of Electric Spark Ignition in Internal Combustion Engines.

By J. D. Morgan. Lond., Crosby Lockwood & Son; N. Y., D. Van Nostrand Co., 1922. 94 pp., diagrs., 9 x 6 in., cloth. $2.25.

In this little book an account is given of the scientific basis of electric spark ignition. During recent years much research

has been undertaken on ignition problems, the main results of which, so far as they are of direct value to designers and students of gasoline engines, are here brought together. The design and constructional details of ignition apparatus have been excluded from this discussion.

SCIENTIFIC MANAGEMENT.

By Horace Bookwalter Drury. 3d edition. N. Y., Columbia University, 1922. (Studies in history, economics and public law). 271 pp., 9 x 6 in., cloth. $2.75. (Gift of Longmans, Green & Co., N. Y.)

Dr. Drury's account of the development of scientific management appeared originally in 1915. In 1918 a revised edition appeared which corrected the errors of the original edition and extended the account down to the latter date. The present edition is substantially a reprint of the 1918 edition, with a long introduction in which later tendencies and the present situation are described.

The volume is divided into two sections, historical and critical. The historical section gives an account of the genesis of scientific management, of the leaders in its development and of the trades and plants that adopted it. The critical section discusses its effect on productivity, on the labor problem and on the worker.

THEORY OF ALLOTROPY.

By A. Smits. Lond., & N. Y., Longmans, Green & Co., 1922. (Textbooks of physical chemistry). 397 pp., diagrs., tables 9 x 6 in., cloth. $7.00.

A detailed presentation of the theory of allotropy originated by Dr. Smits in 1910. The author shows the way in which the phase rule is applied to elucidate the phenomena of allotropy, sets forth the application of the theory to electromotive, photochemical and electrochemical phenomena and summarizes the experimental work carried out to examine it. A careful compilation of our knowledge of the subject is given.

TREATISE ON THE THEORY OF BESSEL FUNCTIONS.

By G. N. Watson. Cambridge, University Press, 1922. 804 pp., tables, 11 x 7 in., cloth. $16.00. (Gift of Macmillan Co., N. Y.)

The author states that this book has been designed with two objects in view. The first is the development of applications of the fundamental processes of the theory of functions of complex variables, for which purpose Bessel functions are admirably adapted. The second is the compilation of a collection of results which would be of value to the increasing number of mathematicians and physicists who encounter Bessel functions in the course of their researches. Such a collection seems to be demanded by the greater abstruseness of properties of Bessel functions which have been required in recent years in various problems of mathematical physics.

While the endeavor has been made to give an account of the theory of Bessel functions which a pure mathematician would regard as fairly complete, the author consequently has also endeavored to include all formulas which, although without theoretical interest, are likely to be required in practical applications. A very full bibliography is included.

TWELVE-HOUR SHIFT IN INDUSTRY.

By Federated American Engineering Societies. Committee on Work-periods in Continuous Industry. N. Y., E. P. Dutton & Co., 1922. 302 pp., tables, 8 x 6 in., cloth. $3.50.

The investigations reported upon in this volume were undertaken by the Federated American Engineering Societies in 1921. The objects were to ascertain the extent of two-shift work in continuous-process industries other than the manufacture of iron and steel, the experience of manufacturers who had changed from two-shift operation to some other system, and to study the technical aspects of changing from the two-shift to the three-shift system in the iron and steel industry.

This volume includes a report on the first two points prepared by Dr. Horace B. Drury and one on the third point by Mr. Bradley Stoughton, as well as a brief general summary of the conclusion to be drawn from their studies. These are favorable to the two-shift system.

WECHSELSTROMERZEUGER.

By Franz Sallinger. Berlin u. Leipzig. Vereinigung wissenschaftlicher Verleger, Walter de Gruyter & Co., 1922. 127 pp., diagrs., 6 x 4 in., boards. $.25.

This booklet is intended, on the one hand, as an introduction to the subject of alternating-current dynamos, and on the other, to give engineers without special electrical training, who are connected with the construction or operation of these machines, an understanding of their essential characteristics. A special effort has therefore been made to explain these characteristics simply and to derive the most used formulas and diagrams.

The windings are first explained, in connection with the generation and calculation of the electromotive force and the armature fields. After the vector diagrams have been derived, the experimental proving and the method of operation are treated. In conclusion data are given on the design, calculation and construction of alternators, with examples of actual machines which show how the formulas and diagrams are used.

PERSONAL MENTION

H. S. HUGHES has been made manager of the United Electric Company, Highland Falls, N. Y.

I. F. KINNARD has recently formed a connection as Research Engineer with the West Lynn Works of the General Electric Company, West Lynn, Mass.

H. T. TEAGUE, formerly with the Ohio Bell Telephone Co. is now connected with the Western Electric Company, 195 Broadway, New York, N. Y.

J. R. WERTH, commercial agent for the Oklahoma Gas & Electric Co., has been appointed a consulting director of the Coal Mining Institute of America.

T. Randall DuBois, formerly with the Birmingham Motors, Ltd., Peterboro, Ont., is now with the engineering department of the New York Central Railroad.

ALBERT G. CRAIG has changed his business affiliation from the United Electric Light & Power Co., New York City, to Popular Radio, Inc., New York City.

DEAN J. LOCKE, formerly Electrical Engineer with Albert S. Richey, Worcester, Mass., has accepted a position with the Public Service Railway Co., Newark, N. J.

J. W. YOUNG has terminated his work with the Hudson Coal Co. of Scranton, Pa., to accept a position in the Electrical Section of the Duquesne Light Co., Pittsburgh, Pa.

A. C. AMES has resigned as Chief Electrician of the Providence Gas Co., Providence, R. I. and has accepted the position of Superintendent of Fire Alarms, Providence, R. I.

G. J. NEWTON has been appointed Chief Engineer of the George Construction Co., Inc., Philadelphia, Pa. He will have charge of all underground distribution work.

G. M. THOMPSON, for the last ten years Superintendent of the Toronto Power Co., Ltd. of Niagara Falls, Ont., has resigned to join McClellan & Junkersfeld, Inc., New York, N. Y.

J. B. HILL, who held the position as professor of Public Utility Relations at the University of Iowa, is now General Manager of the Lincoln Gas & Electric Light Co., Lincoln, Nebraska.

THOMAS R. WEYMOUTH, who gave up his position as Chief Engineer of the United Natural Gas Co., Oil City, Pa. and has become President of the Iroquois Gas Corporation, Buffalo, N. Y.

A. M. BUCK, until recently a member of The Beeler Organization, Consulting Engineers, has been made Associate Editor of *Electric Railway Journal*, McGraw-Hill Publishing Co., New York, N. Y.

LAWRENCE H. CONNELL is now working in the General Electric Company's Research Laboratory, Schenectady, N. Y. He was formerly connected with the Samson Electric Company, Boston, Mass.

V. ZWORYKIN, until recently Electrical Engineer with the C & C Developing Company, Kansas City, Mo., is now in the research department of the Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

E. A. GRAHAM, who for the past nine years has been a member of the engineering staff of the Electric Bond & Share Co., has

been appointed General Manager of that company's holdings in Cienfuegos, Cuba.

Benson M. Jones has resigned as a Service Engineer in the Chicago district of the Westinghouse Electric & Mfg. Co. and is now employed in the engineering department of the Duquesne Light Co., Pittsburgh, Pa.

Harrison D. Panton has severed his connection with the Carolina Power & Light Co., and its affiliated companies and has opened an office at Raleigh, N. C., for the general practise of electrical and mechanical engineering.

A. S. Kalenborn has recently bought a half interest in the Welding Service & Supply Co., San Francisco, Cal., manufacturers of electrical apparatus. His former position was with the Rieber Laboratories, San Francisco.

Hadley F. Freeman has terminated his connection with the Fisk Rubber Company and has formed, with H. E. Smith, the firm of Smith and Freeman for the practise of patent law with offices at 1372 Hanna Bldg., Cleveland, O.

William A. Harding has become identified with the Southern California Edison Co., at Big Creek Hydroelectric Plant, in charge of the mechanical department. His former connection was with the Celite Products Co., in Los Angeles.

Henry Harseim and George W. Scutt, both recently of W. V. Pangborne & Co., Philadelphia, Pa., have formed a copartnership with Oliver S. Kern under the name of the Eastern Electric Construction Co., Ltd., at Philadelphia, Pa.

J. Elmer Housley, who for the past year has been attached to the Sales Office of the Aluminum Co. of America, Kansas City, Mo., has returned to his former position as Electrical Engineer with the Aluminum Ore Co., East St. Louis, Mo.

Robert A. Stott has resigned as Assistant to the Electrical Engineer of the United Electric Light & Power Co. of New York City and has accepted a position as Personal Representative of the President of the Potomac Public Service Co., Hagerstown, Md.

H. P. Sleeper, formerly of the Supply Engineering Department of the Westinghouse Electric & Mfg. Co., has entered the employ of the Duquesne Light Co., Pittsburgh, in its engineering department. He will handle the protective work of this company.

S. G. Gassaway, who for the last three years has maintained consulting offices with Mr. W. G. Williams, specializing in petroleum, has been appointed Field Superintendent of the Production Department of the Lone Star Gas Co. for the State of Oklahoma.

N. C. Husted, who has been with the Seyler Manufacturing Co. of Pittsburgh, Pa. for some time, has returned to the Hubbard Pressed Steel Company, Niles, Ohio, as Manager. He had been connected with this firm for several years prior to his connection with the Seyler Manufacturing Co.

Frederick D. Nims, formerly Chief Operating Engineer with the Mexican Light and Power Company, Mexico, D. F., Electrical Engineer and General Superintendent of the Western Canada Power Company of Vancouver, and later President and General Manager of the Washington Coast Utilities at Seattle, has disposed of his interests in the last named company and is now associated with Parsons, Todd & Co., Boston, as a director in the corporation.

W. Nelson Smith, consulting electrical engineer of the Winnepeg Electric Railway Company and Member of the Institute has just been presented by the Engineering Institute of Canada with the Plummer Medal. This medal is presented each year for the best paper on a chemical or a metallurgical subject. The medal for 1921-22 was awarded to Mr. Smith as joint author with Dr. Shipley of two papers presented during 1921 and 1922 on the self corrosion of cast iron and lead in alkaline soils.

Obituary

Walker G. Wylie, M. D., gynecologist and famous surgeon, died on March 13, 1923, at his home in New York City. He was born at Chester, N. C. in 1849. At the age of sixteen he enlisted in the Confederate Army, and after the war entered the University of South Carolina. Later he received his medical degree from Bellevue Medical College. The next year he studied hospital construction and nurses training abroad and it was from his reports that the first nurses school was established in the United States. Dr. Wylie was a member of the New York Academy of Medicine, the New York County Medical Society, the New York Pathological Society, the New York Obstetrical Society, the American Gynecological Society, the Royal Society of Medicine in London and the American Institute of Electrical Engineers.

William Penn White, for the last eleven years with the General Electric Company at its New York office, died recently in Washington, D. C. Prior to his transfer to the New York office, Mr. White had been connected with this company since his graduation from Lehigh University. He became an Associate of the American Institute of Electrical Engineers in 1912.

Fred G. Dieterich, solicitor of foreign and United States patents, of Washington, D. C. died recently in Washington. Mr. Dieterich was an Associate A. I. E. E.

Walter Schmidt, President and General Manager of the Western Precipitation Company of Los Angeles, Cal., died on February 22, 1923. He became a Member, of the A. I. E. E. in June 1922.

Samuel L. Naphtaly, Associate, A. I. E. E., died after a three months' illness in San Francisco, June, 1922. Born and educated in California, he became associated with some of that State's principal electrical projects and was one of the projectors of the Oakland and Antioch Railway. Later he became Vice-President and General Manager of the Los Angeles Dry Dock Company. In 1922 he entered the services of the Great Western Power Company in San Francisco, where he was Vice-President and General Manager until the time of his death. He was a member of the Society of Naval Architects and Marine Engineers.

Past Section and Branch Meetings

PAST SECTION MEETINGS

Baltimore.—February 9, 1923. Subject: "Important Properties of Insulating Materials and the Theory of Breakdown of Insulation." Speaker: Mr. J. B. Whitehead. Discussion of the paper followed. Previous to the meeting a dinner was held at the Hopkins Club. Attendance 108.

Cincinnati.—February 8, 1923. Subject: "What and Why of the Storage Battery." Speaker: Mr. J. H. Tracey, of the Electric Storage Battery Company. Moving pictures were shown and discussion followed. Attendance 75.

Columbus.—January 26, 1923. Subject: "The Fundamentals of Good Lighting Practise." Speaker: Mr. A. D. Bell of the General Electric Company. Attendance 32.

February 16, 1923. Business meeting.

February 23, 1923. Subject: "Electrical Equipment of Coal Cutting and Loading Mechanism and Electric Mine Locomotives." Speaker: Mr. R. R. Dunlop, of the Jeffrey Mfg. Co. Attendance 14.

Connecticut.—February 21, 1923. Joint meeting with the Waterbury Branch, A. S. M. E. Subject: "Principles and

Practise of Industrial Heating." Speaker: Mr. J. A. Doyle, Vice-President of the W. S. Rockwell Co. of New York. Attendance 90.

Denver.—February 16, 1923. Subject: "Possibilities of Denver as an Electrical City." Speaker: Mr. Frank N. Briggs. Attendance 35.

Detroit-Ann Arbor.—February 19, 1923. Subject: "The Rubber Industry." Speaker: Mr. D. H. Baer, Chief Electrician of the Morgan & Wright Co. of Detroit. Attendance 66.

March 9, 1923. An open session meeting to which ladies were invited. Subject: "Our Sun and Others." Speaker: Prof. R. H. Curtis, Asst. Director of the Observatory of the University of Michigan and Professor of Astronomy. Attendance 215.

Fort Wayne.—February 15, 1923. Subject: "The Testing Laboratory." Speaker. Mr. W. Howard Miller. Attendance 55.

February 23, 1923. There was a trip through the plant of the Northeast Power Station of the Kansas City Power & Light Company, where dinner was served, after which Mr. H. C. Blackwell spoke on the work of this company. Attendance 55.

Kansas City.—March 6, 1923. Subject: "Water Power Possibilities of Southwestern Missouri." Speaker: Mr. E. L. Williams, District Engineer of the Water Resources Branch of the U. S. Geological Survey. Attendance 14.

Lehigh Valley.—February 15, 1923. Subject: "Electric Thermic Equipment for Industrial Purposes." Speaker: Mr. R. D. Thomas. Attendance 35.

Los Angeles.—February 2, 1923. Subject: "Ceramic Developments of Porcelain Insulators." by Mr. Frank Riddle, President of the American Ceramic Society, and "Modern Methods of Firing High-Voltage Porcelain." Attendance 52.

Lynn.—January 31, 1923. Subject: "Measurement of Phenomena of Short Duration." Speaker: Dr. Harvey L. Curtis, of the Bureau of Standards, Washington, D. C. Attendance 150.

New York Section.—The N. Y. Section of the Institute held a meeting at Institute headquarters, 33 West 39th St., New York, on the evening of Wednesday, March 21, 1923. This meeting was held jointly with the Metropolitan Sections of the A. S. M. E., A. S. C. E. and A. I. M. E. The subject of the meeting "Hydroelectric Power for New York" was presented through the medium of a symposium, five speakers taking part, each covering a different phase of the subject. The first, "A Coordinating Statement of the Problem" Col. Scheidenhelm, Consulting Engineer, Mead and Scheidenhelm, N. Y.; "An Approximation of Available Water Power and Cost of Delivery," W. S. Murray, Consulting Engineer, Murray and Flood, N. Y.; "Requirements of Service and Evolution of Hydro Power," G. A. Orrok, Consulting Engineer, New York Edison Co.; "Quality of Hydro Service," F. A. Allner, Gen. Supt., Penn. Water & Power Co., Baltimore; "Reliability of Long Distance Transmission," L. E. Imlay, Consulting Engineer, Niagara Falls Power Co. A discussion followed which was opened by J. P. Hogan, Consulting Engineer with Wm. Barclay Parsons, and W. S. Finlay, Jr., Vice President, American Water Works & Elec. Co., New York. A short general discussion from the floor followed. The attendance was about 875.

Philadelphia.—January 8, 1923. Subject: "Wind Shielding Effects of Line Conductors in Groups." Speaker: Mr. R. B. Mateer, of the Philadelphia Electric Co.

February 21, 1923. Subject: "Recent Developments in the Electrical Industry." Speaker: Mr. L. W. W. Morrow, of the *Electrical World.*

February 27, 1923. Afternoon session. Subject: "Milling Cutters: The Influence of Differences in Design on Power Consumption and Capacity," by Mr. James A. Hall and Mr. Benjamin P. Graves; and "The Design and Construction of Large Machine Tools," by Mr. George H. Benzon. Evening Session. Subjects: "The History of the Machine Tool and its Effect on Present Day Civilization," by Dean Dexter S. Kimball, and "Some Features of the Economic Situation of the Machine Tool Industry," by Mr. Ernest F. DuBrul. There was an address by Mr. John L. Harrington, President, A. S. M. E. Attendance at afternoon session, 126; evening session 240.

March 3, 1923. Subject: "The Relation of the National Electric Code to the Industrial Plan," by Mr. Dana Pierce. This was a joint meeting with the Philadelphia Section of the Iron & Steel Electrical Engineers. Attendance 115.

March 12, 1923. Subject: "Recent Development in Thermionic Tubes," Speaker: Mr. William G. Housekeeper. There was a dinner preceding the meeting. Attendance 82.

Pittsburgh.—February 21, 1923. Subject: There was a symposium on "Meters and Metering," in which Messrs. F. C. Holtz, B. F. Cleaves, and J. A. Malady took part. Attendance 277.

Portland.—February 20, 1923. This meeting was under the auspices of the Pacific Telephone & Telegraph Co., at which there were several short speeches on the new machine switching telephone system. Attendance 210.

Pittsfield.—February 15, 1923. Subject: "The Production of Serviceable Iron Castings." Speaker: Dr. Moldenke. Attendance 125.

March 2, 1923. Subject: "Behind the Screen with the Movie Makers." Speaker: Dr. Rogers, Vice-president and General Manager of the Picture Service Corp. Motion pictures illustrated the lecture. Attendance 500.

March 8, 1923. Subject: "Impressions of Japan." Speaker: Mr. W. W. Lewis, of the General Electric Company who has just returned from several months stay in Japan. Attendance 250.

March 15, 1923. Subject: "Electron Emission from Heated Metals." Speaker: Dr. Irving Langmuir, of the General Electric Company. Attendance 175.

Providence.—March 2, 1923. Subject: "The Modern Oil Circuit Breaker". Speaker: Mr. W. S. Edsall. Attendance 45.

Rochester.—February 23, 1923. Subject: "The Fundamentals of Speech Transmission." Speaker: Dr. Harvey Fletcher. Attendance 130.

Schenectady.—February 2, 1923. Subject: "The Human Voice and Its Electrical Transmission." Speaker: Mr. John Mills. Attendance 190.

Seattle.—January 15, 1923. Three moving picture films were shown: "The Story of an Electric Meter," "Teaming up for First Aid" and "Winning the Race Against Demand." Attendance 45.

February 21, 1923. Subject: "The Queenston-Chippewa Development." Speaker: Mr. R. L. Hearn. Attendance 68.

February 26, 1923. Subject: "The Elementary Theory of Integrating and Demand Meters," Speaker: Mr. F. C. Holtz. Moving pictures and lantern slides illustrated the lecture. Attendance 48.

St. Louis.—February 28, 1923. Social meeting. Attendance 170.

Toledo.—February 16, 1923. Joint meeting with the A. S. M. E. Section. Subjects: "Public Service Law and its Relation to the Engineer," by Mr. M. C. Seeley, and "Leather Belting," by Mr. Louis W. Arny. Attendance 50.

March 9, 1923. Subject: "Industrial Heating." Speaker: Mr. E. F. Collins, of the General Electric Co. Lantern slides accompanied the talk. Attendance 32.

Toronto.—February 9, 1923. Subject: "Loud Speakers and Public Address Systems." Speaker: Mr. H. J. Vennes, of the Northern Electric Co. Attendance 105.

February 23, 1923. Subject: "Power Development at Niagara and the St. Lawrence River." Speaker: Mr. T. H. Hogg. Attendance 108.

Urbana.—January 16, 1923. Subject: "Illumination—Engineering and Sales." Speaker: Mr. J. R. Colville. Attendance 45.

Utah.—February 26, 1923. Subject: "Lightning Arresters.", Speakers: Mr. Plumb and Mr. Ashworth. Attendance 100.

Vancouver.—February 23, 1923. Subject: "Some Features of the Valuation of Public Utilities Bearing Specially on Rate Making." Speaker: Mr. C. W. Colvin. Attendance 16.

Washington, D. C.—February 13, 1923. Subject: "The Physical Nature of Speech and Hearing." Speaker: Dr. R. L. Jones, of the Western Electric Co. Attendance 175.

Worcester.—February 15, 1923. Subject: "Interior Wiring and Illumination." Speaker: Prof. A. L. Cook, of Pratt Institute. There were illustrations by lantern slides. Attendance 40.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—February 17, 1923. Subject: "The Necessity for Managerial Ability in the Practise of Engineering." Speaker: Mr. A. Kling. There were talks by Mr. R. C. Dickenson on "Starting Equipment for Motors" and Dean J. J. Wilmore on "The New Engineering Building to be Constructed at this Institute." Attendance 17.

March 3, 1923. Subjects: "What the World Expects of a College Trained Man," by Dean Rupert Taylor, and a synopsis of two addresses by Dr. J. A. L. Waddell delivered at Barcelona, Spain, presented by Mr. Andrew Malone. Attendance 19.

University of Alabama.—March 6, 1923. The subjects of "The Underwriter's Code," "The National Electric Code," and "Static Charge and Discharge" were presented and discussed by various students. Attendance 11.

University of Arizona.—February 21, 1923. Mr. W. J. Cressingham gave a talk on "The Development of the Bell System," accompanied by moving pictures. Mr. M. A. Schuele gave a talk on the life of C. P. Steinmetz. Attendance 21.

Armour Institute of Technology.—February 15, 1923. Subject: "A Problem in Engineering." Speaker: Prof. Nash. Attendance 45.

March 1, 1923. Subjects: "Tools of the Brain Worker," by Mr. H. K. Randall, and "Design of Telephone Circuits as Compared with that of Power Circuits," by Mr. A. F. Grenell. Attendance 43.

University of California.—February 7, 1923. Subject: "Remote Control of a Newspaper Press." Speaker: Mr. R. P. Thompson. Attendance 32.

February 21, 1923. Initiation of new members. Mr. Metcalf gave a talk on the Magnavox. Attendance 72.

March 3, 1923. Inspection trip to the Patrero Substation of the Pacific Gas & Electric Co. Attendance 35.

March 7, 1923. Inspection trip to the Oakland Exchange of the Pacific Telephone & Telegraph Co. Attendance 49.

Carnegie Institute of Technology.—February 15, 1923. Subject: "Power Development on the Orient." Speaker: Mr. Stephen Hayes. Attendance 60.

Case School of Applied Science.—February 13, 1923. Subject: "The Design of an Outside Telephone Plant." Speaker: Mr. E. F. Biggert. Attendance 23.

University of Cincinnati.—March 1, 1923. Subject: "The West End Power Plant of the Union Gas and Electric Co." Speaker: Mr. Wm. F. Demkle. Attendance 80.

Denver University.—March 8, 1923. Organization meeting. The following officers were elected: Chairman, Mr. Laurence W. Thomson; Vice-Chairman, Mr. C. A. Dingham; Secretary and Treasurer, Mr. Ray Hoover. Nineteen students were present, all of whom became charter members of the Branch. The aims and activities of the A. I. E. E. were explained to the students by Dr. R. E. Nyswander, Professor of Physics and Director of the School of Engineering at this university.

Iowa State College.—January 31, 1923. Joint meeting with the Chemical Engineering Society. Subject: "The Relation of Electricity to the Chemical Engineer." Speaker: Dr. O. R. Sweeney. The lecture was followed by a three-reel film entitled "Triplex Process of Making Steel." Attendance 205.

February 7, 1923. Subject: "Transmission Line Development in Iowa." Speaker: Mr. A. B. Campbell, Electrical Engineer for the State Board of Railroad Commissioners for Iowa. Attendance 144.

February 28, 1923. A five-reel moving picture was shown entitled "From the Jungle to the Transmission Line." The film was loaned by the Okonite Co. Attendance 88.

University of Iowa.—January 29, 1923. Business meeting. Attendance 50.

February 5, 1923. Subject: "Treatment of Run-Down Storage Batteries," by Mr. Chas. Sullivan, "Influence of Horn and Diaphragm on Sound Waves in a Radio Loud-Speaker," by Mr. H. E. Fetig, and "How a Telephone Call Goes Through a Central Office," by Mr. H. K. Shore. Attendance 50.

February 12, 1923. Papers by various students were given on the subjects of "Pitt River Power Development," "Interurban Substations" and "Farm Power." Attendance 50.

Kansas State College.—February 26, 1923. Business meeting. Attendance 49.

University of Kansas.—February 14, 1923. Subject: "My Work with The American Telegraph and Telephone Company." Speaker: Mr. Harold W. Anderson. Attendance 51.

March 1, 1923. Subject: "Automatic Substations." Speaker: Mr. Clark Davis. Attendance 47.

Lafayette.—February 10, 1923. Review of subjects from current periodicals given by various students. Attendance 21.

February 24, 1923. Prof. King gave a talk on the A. I. E. E. Midwinter Convention. Attendance 20.

March 3, 1923. Review and discussion of current periodicals by various students. Attendance 19.

March 10, 1923. Review of current periodicals by students. Attendance 21.

Lewis Institute.—January 19, 1923. Shop trip through the Chicago Theatre, Chicago, Ill. Attendance 23.

February 11, 1923. Social meeting and initiation of new members. Attendance 17.

February 23, 1923. Subject: "Recent Developments in Long Distance Telephony." Speaker: Mr. W. C. Hall. Attendance 70.

Marquette University.—February 13, 1923. Subject: "The Electrical Units and the Manner in Which They are Reproduced and Maintained." Speaker: Prof. F. A. Kartak. Attendance 28.

Michigan Agricultural College.—January 31, 1923. Subject: "Niagara Falls and the Power Companies of Niagara." Speaker: Mr. O. D. Dales. There were moving pictures and lantern slides were shown. Attendance 50.

February 23, 1923. Subject: "A Trip Through Japan and China." Speaker: Mr. S. Q. Hayes. Attendance 33.

February 27, 1923. Subject: "The Economics of Engineering." Speaker: Mr. H. P. Seelye, Distribution Engineer for the Detroit Edison Co. Attendance 35.

University of Minnesota.—February 14, 1923. Subject: "Central Station Problems." Speaker: Mr. F. D. Crocker, Asst. Vice-president, Northern States Power Co. Attendance 60.

March 1, 1923. Subject. "Railway Electrification." Speaker: Mr. E. R. Martin. Attendance 48.

University of Missouri.—February 12, 1923. Subject: "Electricity on the Farm." Speaker: Mr. Neil K. Barr. Attendance 19.

February 26, 1923. Subject: "Distribution Engineering." Speaker: Mr. Paul W. Kiesling. A moving picture entitled "Conquest of the Forest" was shown. Attendance 30.

March 8, 1923. An educational moving picture "King of the Rails" was shown, after which there was a brief talk by Mr. H. C. Feuers on "The Young Engineer Starting in Industry." Attendance 30.

Montana State College, March 6, 1923. Subject: "Inductive Interference in Telephone Transmission Lines." Speaker: Mr. E. Hatterick. Attendance 120.

University of North Dakota, February 26, 1923. Subject: "Heat Balance in Power Plants." Speaker: Prof. G. B. Wharen. Attendance 17.

Northeastern University.—This branch was organized in February with the following officers: Chairman, Mr. Burton F. Keene; Vice-Chairman, Mr. Levi G. Cushing; Secretary, Mr. Leon F. Hubby; Asst. Secretary, Mr. Raymond I. Sawtell, all enrolled students of the A. I. E. E.

University of Notre Dame.—February 20, 1923. Subject: "Direct Vs. Alternating Current for Traction Purposes." Speaker: Mr. Francis X. Egan. Attendance 20.

March 5, 1923. Subject: "Storage Batteries." Speaker: Mr. Paul Sagstetter. There was also a talk by Dr. R. R. MacGregor on the electrical possibilities in New Zealand. Attendance 30.

Ohio Northern University.—Engineers' Week, February 19-24, inc., during which time the lectures of electrical engineering interest were "Telephone Engineering Cost Studies," by Mr. J. P. Kobrock and "Electrical Aids to Greater Production," by Mr. G. A. Hughes.

March 8, 1923. Subject: "The Theory of Radio Communication." Speaker: Mr. Witzler. Attendance 14.

Ohio State University.—February 23, 1923. Subject: "Etiquette." Speaker: Miss Elizabeth Conrad. Attendance 50.

Oklahoma A. & M. College.—February 8, 1923. Subject: "How We Can Benefit Our School as an Organization." Speaker: Mr. F. A. Todd. There was also a talk on the benefits derived from membership in the A. I. E. E. Attendance 15.

University of Oklahoma.—March 8, 1923. Subjects: "The Keokuk Power Company," by Mr. John Wallis, "Description of the Inspection Trip Through the Armour Packing Co. at Chicago," by Mr. J. W. Lamar and "Description of a Trip Through the Norburg Mfg. Co. at Milwaukee, and of the Nash Motor Co.," by Mr. E. H. Reid. Attendance 20.

University of Pittsburgh.—January 26, 1923. Subject: "The Harvesting of Natural Ice." Speaker: Mr. R. B. Anthony. Attendance 26.

February 2, 1923. Subjects: "A Comparison of the Westinghouse Electric Locomotives and the General Electric Locomotives, Both of Which are Operated on the Chicago, Milwaukee and St. Paul R. R.," by Mr. G. T. Craig and "My Experiences with the Pittsburgh Transformer Co.", by Mr. W. T. Ackley. Attendance 31.

February 9, 1923. Subject: "The Operation of Oil Wells." By Mr. R. N. McMichael. Attendance 32.

February 16, 1923. This was a joint engineering meeting.

February 23, 1923. No meeting due to a 24-hour efficiency run.

Purdue University.—February 13, 1923. Subject: "University Conditions in Scandinavia." Speaker: Mr. A. T. Strom. The lecture was illustrated with lantern slides. Attendance 22.

February 28, 1923. Subject: "Carrier Current Telegraph and Telephone Systems," by Mr. H. A. Affel, of the A. T. & T. Co. Attendance 95.

Rensselaer.—February 13, 1923. Subject: "Magnesium, Its Manufacture and Use." Speaker: Mr. Safford K. Colby, President of the American Magnesium Corp. Attendance 165.

Rutgers.—February 15, 1923. Joint meeting with student branches of A. S. C. E. and A. S. M. E. Subject: "Leonardo de Vinci." Speaker: Mr. John W. Lieb. Attendance 150.

School of Engineering, Milwaukee,—February 23, 1923. Subject: "Sale of Illumination." Speaker: Mr. Leonard V. James. Attendance 32.

University of Southern California.—February 22, 1923. Subject: "The Luguna Bell Substation and the 220 kv. Lines of the Southern California Edison Co." Speaker: Mr. Mayer, of the Southern California Edison Co. Attendance 10.

Stanford University.—February 20, 1923. Business meeting. Attendance 16.

Swarthmore College.—February 23, 1923. Papers on the following subjects were read: "Electrification of Steam Railways, by Mr. Edward A. Green, "The Development in the Electrical Industry During 1922," by Mr. J. Howard Thompson, and "Some of the Elements of Air Flow in Electrical Machinery." Attendance 10.

March 2, 1923. Dr. Fussell of the Engineering Dept. spoke on the A. I. E. E. Midwinter Convention. Attendance 8.

March 9, 1923. Joint meeting with the student branches of A. S. M. E. and A. S. C. E. Subject: "Stokers." Speaker: Mr. Walter Strunk. Attendance 30.

Syracuse University.—February 16, 1923. Subjects: "Electrification of Railroads," by Mr. Paul Moore, and "Alinement Charts," by Mr. Sidney Maunder. Attendance 19.

February 23, 1923. Subject: "Electric Propulsion of Ships." Speaker: Mr. Stafford. Attendance 18.

University of Texas.—February 5, 1923. Two moving pictures were shown "Back of the Button" and "After Fish on Horseback." Attendance 16.

Virginia Military Institute.—February 7, 1923. Subject: "Electric Propulsion of Ships." Speaker: Mr. R. L. Gatewood. Attendance 34.

February 15, 1923. Joint meeting with local branch of A. S. M. E. Subject: "Scientific Use of Concrete." Speaker: Col. H. C. Boyden. The lecture was illustrated. Attendance 100.

University of Virginia.—February 1, 1923. The following papers were presented: "Some Advantages of Electrification of Steam Railway Trunk Lines in This Country," by Mr. W. M. Abbott, "A Narrow-Gage Electrified Railway in South America," by T. R. Bunting, "Old Water Wheels of Paris," by Mr. F. E. Davis, and "Manner in Which Electric Shocks Affect the Human Body," by Mr. M. A. Cohen. Attendance 16.

February 15, 1923. Subject: "Some Fundamentals of Modern Artificial Illumination." Speaker: Mr. Samuel G. Hibben, of the Westinghouse Electric & Mfg. Co. Attendance 44.

University of Washington.—February 6, 1923. Subject: "Management Engineering." Speaker: Mr. William Russell. Attendance 24.

March 6, 1923. Subject: "Recent Construction in Transmission and Distribution." Speaker: Mr. Magnus T. Crawford, of the Puget Sound Power & Light Co. Attendance 30.

West Virginia University.—February 26, 1923. Papers were presented: "Voltage Drop Caused by a Blown Fuse in a Three-Phase System," by Mr. R. K. Park, "The Autovalve Lightning Arrester," by Messrs. Ira A. Pitsenberger and Ira O. Myers, "Mr. Edwin H. Armstrong and Radio Telephony," by Mr. C. B. Hutson, "Transatlantic Radio Telephony," by Mr. Charles Snyder, "Limitations of Thermo-couples," by Mr. Alfred Chobaurel, "Electrons and Hot Filament" by Mr. C. W. Addis, "Comparison of A-C. and D-C. Systems," by Mr. Lee D. Tobler and "Artificial Rain Making," by Mr. C. R. Lame. Attendance 27.

University of Wisconsin.—February 14, 1923. Election of officers and other business. Attendance 43.

February 28, 1923. Subject: "Electron Tubes," Speaker: Mr. E. M. Terry, of the Physics Dept. Attendance 63.

Yale University.—February 21, 1923. Subject: "Electric Light and Power, Yesterday, Today and Tomorrow." Speaker: Mr. Aylesworth, of the National Electric Light Association. Attendance 80.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed ***EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the National Societies of Civil, Mechanical, Mining and Electrical Engineers.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to ***EMPLOYMENT SERVICE,*** *as above.*

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

OPPORTUNITIES

ELECTRICAL ENGINEER with several years experience on design, development and application of small or medium size industrial motors. Must be able to obtain independent results by analysis and experiment. Permanent position with old established company. Application by letter stating experience fully. Salary not stated. Location, Pennsylvania. R-368.

TRANSMISSION LINE DRAFTSMAN wanted by a large power company in western Penna. Must be able to work up all field notes, use sag tables and charts and design structures for long spans. Prefer one who could qualify as squad chief. Application by letter. Salary not stated. R-458.

PARTNER with engineering ability ready to invest $10,000 part of which could be paid over a period of several months, desired for long established prosperous business. Owner of business unable to care for present organization and expansion. Application by letter. Location, New York City. R-462.

ELECTRICAL ENGINEER to act as illuminating engineer. Must have at least seven years public utilities experience, particularly research work along illuminating lines. Position permanent. Application by letter. Salary not stated. Location, Pa. R-466.

ELECTRICAL ENGINEER to assist handling electrical work in connection with electrical machinery breakdown insurance. Must not be over 35 years of age, technical graduate preferred, preferably man who has taken student course at some one of the large electrical manufacturing concerns. This should have been followed by some operating experience. Some executive ability. Moderate salary until insurance practises have been learned. Application by letter. Salary not stated. Location, New England. R-486.

INSTRUCTOR in Physics for the session 1923-1924. It is expected to make the appointment to the position permanent after one year's satisfactory service. Must have had 2 years of graduate study and 1 year of teaching experience. Additional study or experience in teaching or applied science is desired, but not required. Duties will be to share in giving the courses in Physics and assist in the electrical engineering dept., if necessary. Total scheduled hours of teaching will not be more than 18 per week, and probably less. Exact assignment to duty will depend somewhat on training and desires of the appointee. Application by letter. Salary not stated. Location, South. R-489.

ELECTRICAL ENGINEER with a-c. and d-c. motor experience to write specifications and make changes in windings and redesign when necessary. Experienced men only considered. Application by letter. Salary not stated. Location, N. J. **R-491.**

ELECTRICAL ENGINEERING GRADUATES having not less than 7 years experience in substation design, switchboard design, etc. Application by letter. Location, Pa. R-492.

MAN experienced in lamp testing to act as inspector at manufacturing plant, representing purchaser of large quantities. Prefer not to have G-E man. Application by letter. Location, Canada. R-493.

TECHNICAL EDITOR in research laboratory to review manuscripts of both technical and popular nature, and act as editorial critic to a staff of eighty scientists. Must have university education, preferably in some branch of engineering, with special training in English; proven ability in editorial work, or in the teaching of English composition to engineers; familiarity with publishers' and printers' requirements, keen perception; tact; unusual thoroughness. Application by letter. Location, Wisconsin. R-500.

EXPERIENCED HYDROELECTRIC ENGINEER for service in Northern New York. Application by letter. R-504.

MECHANICAL or ELECTRICAL ENGINEER SALESMAN to open office in Chicago as exclusive representative of well established mechanical equipment manufacturer. Excellent opportunity to develop this territory to support a considerable selling force. Man under 35 desired. Application by letter giving all necessary information. Salary not stated. Headquarters, Pa. R-517.

ENGINEER with central station and steam power plant design. 3-5 years experience. Some drafting, specification and operating. Knowledge of power plant equipment, valves, piping, etc. essential. Application by letter. Location, N. Y. C. R-524.

ELECTRICAL ENGINEER for power plant drafting, transmission lines. Application in person. Location, Maryland. R-529.

CHIEF ENGINEER for 15,000-kw. steam plant. Must be under 40 years old. Application by letter. Location, Pa. R-557.

GENERAL FOREMAN for foundry, machine, blacksmith, and car shops, employing 150-200 men on repairs and manufacture of equipment for coal mining operation. Age 25-35, technical graduate preferred, with practical knowledge of branches indicated, and executive and production experience. Application by letter stating age, education, experience, salary required and personal data. Location, Pa. R-558.

COMMERCIAL SWITCHBOARD ENGINEER. Capable of handling engineering and commercial features of negotiations involving purchase of power station switchboards, and modern high-powered oil switching equipments, including high voltage and outdoor equipments. Application by letter giving training, experience and state salary expected. Location, Pa. R-559.

DESIGNER for steam and electric power plant. Present plant is 25,000 kw. and is to be built up into 50-60,000 kw. Application by letter Salary not stated. Location, Wyoming. R-584.

RECENT GRADUATE, Civil, Electrical, Industrial or Mechanical Engineering, for planning and scheduling work in Standardization Division. Affords an excellent opportunity to apply engineering training in a broad way, to general business administration as well as learn the various phases of publishing. If possible desire a man who has had very little, if any, business experience. Application by letter. Salary not stated. Location, Pa. R-613.

DESIGNER with power house, substation and electrical distribution experience, Must do own drafting. Application by letter. Location, Canada. R-627.

DRAFTSMAN experienced in power house and substation layouts. Application by letter. Salary not stated. Location, Alabama. R-631.

ELECTRICAL DRAFTSMAN. Men with some experience designing and detailing in connection with the planning of electrical installation in generating stations and substations. Application by letter giving age, experience and salary wanted. Location, Illinois. R-632.

ELECTRICAL DRAFTSMEN on wiring and substation equipment particularly pertaining to coal mines. Application by letter. Salary not stated. Location, Illinois. R-666.

SEVERAL ELECTRICAL ENGINEERS experienced on design and construction of electrical distribution systems for work on perpetual inventories of electrical plants. Knowledge of accounting desirable. Need underground and plant construction men. Application by letter. Location, N. Y. C. R-668.

FOREMAN with long experience in the manufacturing of high-voltage insulators (above 100,000 volts) particularly familiar with the mechanical equipment of such manufacturing. Application by letter. Salary not stated. Location, N. Y. C. R-670.

FOREMAN with thorough training and experience in the manufacture of high-voltage insulators familiar with the chemical and thermal processes of the production. Application by letter. Salary not stated. Location, N. Y. C. R-671.

SPECIALIST in insulating materials, particularly familiar with bakelite. Application by letter. Salary not stated. Location, N. Y. C. R-672.

ENGINEERING GRADUATES to fill positions in various departments of telephone company with good opportunity for advancement. Should be not more than four years out of college, ambitious, have good common sense and engineering ability. No previous experience is necessary. Application by letter. Salary not stated. Location, Pa. R-676.

GRADUATE IN ELECTRICAL ENGINEERING with one or two years experience with public utilities wanted as Assistant to Superintendent of Transmission in charge of operation

and maintenance of transmission lines and substations for a large eastern public utility. Application by letter. Salary not stated. R-695.

TECHNICAL GRADUATES, preferably experienced along electric power plant work. Application in person. Salary not stated. Location, N. Y. C. R-714.

POWER PLANT DRAFTSMAN. Should be able to lay out in detail complete power plant from start to finish. Application by letter. Location, Ill. R-716.

ELECTRICAL ENGINEERING EXECUTIVE. Must know all electrical supply houses in N. Y. to take charge of entire plant. Sign experience desirable. Application by letter. Salary not stated. Location, N. Y. R-731.

ELECTRICAL ENGINEER. experienced on construction and operation of electrical transmission lines up to 22,000 volts, on 3-phase. Must be able to stay on as maintenance man. Application by letter. Location, Va. R-732.

INSTRUCTORS in growing Electrical Engineering Department of state institution of high rank in Middle West. Positions will pay from $160—180 per month, depending on experience and training of those selected. Well recommended graduates from good institutions of 1923 will be considered, but applications are desired for one of the openings from those with some teaching experience. Application by letter giving references in first letter and experience in chronological order. R-824.

SALES MANAGER in full charge of the territory which consists of the western half of Pennsylvania, a good portion of W. Virginia and part of Ohio. Position does not require constant traveling, although frequent visits into the territory are necessary. Graduated electrical engineer, preferably with practical shop training. Salary and bonus. Application by letter. Headquarters, Wisconsin. R-820.

MEN AVAILABLE

ELECTRICAL LABORATORY ENGINEER. 14 years' experience electrical and magnetic measurements, and general technical and research work, desires position in charge of work, or as assistant to party in charge. Have held responsible positions in past. Specialized considerably on magnetic materials, (2 years at steel mills; past member A. S. T. M. committee magnetic properties; etc.) Age 36, single, technical education, minimum salary start $175.00. Eastern locality preferred. E-4199.

ERECTION SUPERINTENDENT with broad experience unloading transporting, installing and repairing power house and substation machinery, high-tension switch and bus structures, switchboards, instruments, etc. Also extensive industrial installations, both mechanical and electrical including compressors cranes, blowers, pumps, piping, etc. Technical education. Former officer Engineer Corps, U. S. Army. Available immediately. E-4200.

PRACTICAL, TECHNICAL ELECTRICAL ENGINEER. 4 years' G. E. and Allis-Chalmers Test, erecting and operating experience. Experienced superintendent of maintenance, power and efficiency operation, desires position as assistant superintendent, or superintendent of power, maintenance or like responsible position. Available at once. E-4201

CHIEF ELECTRICAL DRAFTSMAN, technical graduate with several years' experience on ship electrical plans, calculations, estimates and in supervision of drafting force seeks new position in similar or equivalent line. Available about April 1, 1923. Best of references. E-4202.

ELECTRICAL ENGINEER, age 29, university technical graduate, 2 years' steam engineering and combustion experience in the U. S. Navy, 1 year power plant and substation design and layout, 5 years lighting and power design and installation for commercial and industrial plants. Desires position with consulting engineer or superintendent of electrical construction. E-4203.

YOUNG ELECTRICAL ENGINEER, receiving B. S. in E. E. degree from Iowa State in June 1923 and having some experience in power plant practise and general contracting, would like to become connected with a firm of electrical contractors. Salary no object. Available June 15th. E-4204.

RESEARCH DIRECTOR. Engineer experienced in the managing of organized research, desires to secure position as research director. Can organize new research department or manage one existing. Has managed large cooperative research organization and has wide contacts with engineers. E-4205.

RADIO ENGINEER desires permanent location with radio research or manufacturing concern. Several years contact with radio field; operating, research, teaching and merchandising. Unquestionable references furnished. Managerial ability. Past 24 months employed as New Business Manager of public utility operating over 60 mil, 6-city, system. E-4206.

YOUNG MAN desires permanent position in electrical department of a progressive concern. 25 years of age, university graduate with degree in electrical engineering. Fifteen months' experience in General Electric test, followed by one year as a practical electrician. Student of the Alexander Hamilton Institute business course. Available at once. Location not essential, west preferred. E-4207.

ELECTRICAL ENGINEER AND PHYSICIST, age 31, graduate and post-graduate degrees from leading universities, at present Assistant Professor of Electrical Engineering and Physics in large institution, open for consideration of new position. Thorough knowledge of mathematical and experimental physics; research experience includes period at Bureau of Standards and commercial laboratory work, also experience as examiner in Patent Office. Specialist in radio communication. Member, American Physical Society. Will consider responsible research position or Associate Professorship. E-4208.

UNIVERSITY GRADUATE, receiving B. S. in E. E. degree in June, 1923, desires connection with a reliable manufacturing or consulting firm. Knowledge of accounting and general business training. Speaks foreign language. Hard worker (self educated). Age 25. Location immaterial. Available June 15. E-4209.

ASSOCIATE PROFESSOR OF ELECTRICAL ENGINEERING desired, $3200. Five years' practical experience in central stations, power plant, distribution and commercial branches. Telephone engineering, switchboards, cable testing. Seven years' responsible teaching. Degree, M. E. 1910. Qualified to teach theory and practise of Electrical Engineering, Commercial Engineering and Communication Engineering. E-4210.

ELECTRICAL ENGINEER, age 41, married, graduate Cornell University, Westinghouse apprentice, 17 years' experience in electric railway, hydroelectric, mining and industrial applications, and in electric property valuation work. At present in business under own name as consulting electrical engineer on Pacific Coast. Desires position with well established firm of consulting engineers or with contracting, mining or industrial concern. E-4211.

ENGINEERING MANAGER, with wide experience, G. E. test, G. E. switchboard and station layout design with prominent consulting engineers, commercial work, design and construction of distribution systems, now managing successful municipal system, wishes to secure management or responsible situation with larger system. E-4212.

EXECUTIVE-SALES ENGINEER, technical graduate desires connection in sales department of progressive manufacturing concern located in middle west. Twelve years' experience in executive and sales work with large electrical manufacturer. E-4213.

MECHANICAL AND POWER ENGINEER, B. S. and M. E. eight years' broad experience, machine shop, metallurgy, sugar refinery design and layout, industrial and power plant practise, operation, design, layout, calculations, heat balance, steam, water, power requirements, etc. investigation, reports. Desires responsible connection of high type. E-4214.

ELECTRICAL ENGINEER, technical graduate 1918, two years operation design, and construction of electrical power plants, two and one half years in design and manufacturing of switchboards and panel boards. Desires central station work with private company, or with consulting or contracting engineers. Location preferred, Missouri or farther west. Age twenty nine, married, salary $3600. E-4215.

PROFESSOR OF ELECTRICAL ENGINEERING, with B. S. and E. E. degrees from major universities, two years' post-graduate work. Four years, factory test and design experience. Eighteen months in charge of high-tension line and substation construction. Eight years' consulting and teaching experience. Age 38, married. Desires more responsibility for Electrical Design courses than now held. Available Sept. 1, 1923. E-4216.

YOUNG ELECTRICAL ENGINEER, single. receiving M. S. degree from Mass. Inst. of Tech. in June, wishes to become connected with some power company having high-tension transmission lines. Understands French, German and Spanish, Student member of A. I. E. E., 15 months G. E. Co. test. Master's thesis is on a-c. transients on a smooth artificial transmission line. E-4217.

PROFESSORSHIP OR ASSOCIATE PROFESSORSHIP, desired in electrical engineering. Two years power plant operation and maintenance, Lt. signal corps, U. S. Army. Three years teaching, last two in charge of Electrical Engineering Laboratory instruction in well known technical institution. B. S. in E. E. and M. S. E-4218.

ELECTRICAL ENGINEER, 25, married, experienced in hydroelectric operation, electrical maintenance, plant engineering and construction, with initiative and executive ability, desires position as electrical superintendent or plant engineer with manufacturing concern. 3 years' G. E. test. Employed as Electrical Supt. and Plant Engineer in paper mill. Preferably Eastern States. E-4219.

ELECTRICAL ENGINEER. Technical graduate, 1912. Comprehensive experience in responsible capacities with selection, installation and operation of modern motor and control applications, and power generation, as applied to steel mills. Desires permanent and responsible position with progressive steel plant or similar organization, or with established consulting electrical engineer. Age 33. Married. Member A. I. & S. E. E. Registered Professional Engineer State of Pennsylvania. At present employed. E-4220.

SUPERINTENDENT. Electric light and power plant, water works, street railway, gas plant, or combination of above utilities. Electrical and Mechanical Engineer, 36 years old, married; American. 12 years' practical experience, design, construction, valuation and operation of above named utilities addition to technical education, location, South, Middle West or foreign. Salary $3000. Available on ten days' notice. E-4221.

ELECTRICAL ENGINEER. Technical graduate, age 31, Westinghouse test and railway engineering experience. Two years, operation maintenance and construction substation, transmission and distribution systems, rolling mills, cranes and electric furnaces. Four years, instructor and assistant professor of Electrical Engineering. Available July 1st, New York vicinity preferred. E-4222.

SUMMER EMPLOYMENT DESIRED BY INSTRUCTOR IN ELECTRICAL ENGINEERING at well known state university in middle west. Experience includes Westinghouse

student course and test floor work, radio work in Air Service and two years of teaching in laboratory and power plant design. Construction, design, operation or other work desired with view of permanent connection in a year or two. Moderate salary sufficient. E-4223.

CERTIFIED TECHNICAL PATENT EXPERT, patent investigator and patent specification writer and prosecutor. Experienced lawyer, patent, solicitor, technical expert and engineer. Act. Mem. the Society American Military Engineers. Desires connection with opportunity to earn $5000 per year. E-4224.

ELECTRICAL ENGINEER (M. E. and Ph. B. degrees,—specialized in electrical engineering) U. S. citizen; several years' practical experience; desires associate or assistant professorship of electrical engineering in North America or where the English language is usually spoken; single; age 38. E-4225.

MECHANICAL ENGINEER desires position as chief draftsman or engineer in charge of design, 32 years old. Cornell graduate, 1912. Seven years designing, paper mills and hydroelectric plants. Seven months construction superintendent. Present salary $3000. E-4226.

ELECTRICAL ENGINEER, receiving B. S. degree in June 1923. Four and one-half years substation construction and maintenance and power dispatching for large electric railway system. One year at same work with large light and power company. Available July 1. Age 27. E-4227.

TECHNICALLY EDUCATED MAN, 32 years of age, is looking for a business opportunity in electrical line. Can invest up to $4000 and services in a clean cut and paying business. The best of references furnished and expected. Sales, power or construction opportunity desired. E-4228.

NIGHT WORK, Mechanical, Electrical Engineer, employed through the day, would like 2-4 hours evening work in power house or as instructor. E-4229.

SALESMAN OR SOLICITOR for house wiring contracts. Location, New York, New Jersey or New England States. Compensation: salary or commission. Technical school and electrical experience. At present employed. Available April 15th. E-4230.

SALES ENGINEER—34 years old, graduate electrical engineer with personality and aggressiveness. Ten years' experience construction and selling building and electrical supplies. Large acquaintance among architects, contractors, builders and dealers, Metropolitan and Long Island, would like to become associated with a rated concern. Will furnish car. E-4231.

ELECTRICAL CONSTRUCTION FOREMAN, Canadian, age 36, married. Twenty years' experience construction, maintenance and operation. Central stations, substations and industrial plants. Both steam and hydroelectric. Desires position in Canada, Niagara, district of Ontario preferred. Best references. E-4232.

ELECTRICAL ENGINEER, technical graduate with B. S. degree, and practically no experience, desires employment. Salary not primary object. Willing to go anywhere. E-4233.

ELECTRICAL ENGINEER. Age 31. Married. Graduate 1916. Experienced with G. E. coal mining concern, public utilities in layout, design, construction of electrical structures for power generation, transmission, application and control. Desires connection with steel company or concern having heavy, large scale power applications. Object of change, more responsibility. Location, Pittsburgh or district. Salary, $3600. E-4234.

ELECTRICAL ENGINEER, 1922 graduate, seeks good opening with a concern, preferably in N. Y. City. Experience in service division of public utility company; at present employed. Will consider both commercial and technical positions. E-4235.

ELECTRICAL ENGINEER, age 34. General Electric test and 11 years' experience on the design, construction and operation of stations, substations, transmission and distribution systems. Desires position with consulting engineer or large holding company. E-4236.

ENGINEER—E. E., 1917. Westinghouse test and engineering department. Industrial engineering and teaching experience. Business training. Desires position in executive capacity or as betterment engineer. Available within reasonable time. E-4237.

YOUNG MAN, twenty-six, E. E. degree 1921, with engineering and business experience, wishes to join an organization offering an opportunity for a career in engineering or allied work. E-4238.

SALES ENGINEER—Experienced technical graduate desires position as sales representative or district agent in N. Y., N. J. or eastern Penna., with well established company offering a high grade electrical product of merit. Salary and commission. Available one month. E-4239.

ELECTRICAL ENGINEER, age 30, technical graduate, desires position. 8 years' experience, exclusive college course, in construction, maintenance and operation of hydroelectric and steam plants, a-c. and d-c., storage battery, Diesel motor plants and other oil-burning motors, high-voltage transmission lines and light and power distribution. At present employed but available on short notice. Location immaterial, no objection to going to foreign country. E-4240.

SALES ENGINEER AND REPRESENTATIVE desires connection with manufacturer of high and low-tension switching and distribution equipment. Experienced in the design of substations and the sales of related equipment. E-4241.

ELECTRICAL ENGINEER, technical graduate, married. G. E. test and engineering and four years in design, construction and operation of large radio stations. Now employed but desires change to position where he can make permanent residence. E-4242.

TECHNICAL GRADUATE, B. S. in E. E.; Assoc. A. I. E. E., age 25, single. Has broad training in fractional horse power motor production, designing and estimating on electrical construction work. Desires position with a concern where theoretical and practical training can best be utilized. Willing worker, easy to get along with. Location immaterial. E-4243.

MANAGER experienced in every branch of electric public utility; engineering, construction, sales and management. Well versed in development of industrial power business, production of good service, satisfactory relations with customers and public. Technical graduate. E-4244.

ELECTRICAL ENGINEERING graduate, at present and for the past three years successfully carrying on the design of large industrial substations, a-c. and d-c. switchboards and safety engineering work, and three years design of electrical measuring and testing instruments. Desires connection with engineering or manufacturing company anywhere in the east or middle west, although middle eastern states preferred. Salary dependent upon location. E-4245.

UNIVERSITY technical graduate receiving degree of E. E. this June desires an opportunity with an engineering firm, power company or electrical apparatus manufacturing company. Now completing teaching fellowship term of two years at a middle west state university. Subject of thesis: "The Application of Radio Telephony to Power Transmission Lines." Willing to go anywhere. Can supply very good references. Age 24, unmarried. Available July 1st. E-4246.

MANUFACTURERS' SALES AGENT, thoroughly reliable, graduate engineer, age 37, with established facilities (30 Church St., N. Y. C.) experience, connections, ability and energy for getting business on technical lines in New York City district, seeks good line for immediate exploitation. E-4247.

EXECUTIVE. Construction, operation and maintenance, electrical and mechanical equipment, design, purchasing, also management of electrical merchandising, and automotive lines. Wide experience central station and industrial plants economical handler of labor and material. E-4248

ELECTRICAL ENGINEER & MECHANICAL DRAUGHTSMAN. University Tech. Grad. (London) Assoc. A. I. E. E., 28, desires connection in San Francisco in vicinity with manufacturing or sales organization. 8 years practical and technical experience in generations and industrial applications of electricity. Some experience instructing a-c. and d-c. arithmetic. Employed but desires betterment. Salary $180 minimum. E-4249.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED MARCH 16, 1923

ABBINK, JOHN, Business Manager, "Ingenieria Internacional," McGraw-Hill Co., 10th Ave. & 36th St., New York, N. Y.

ACLY, HARRY MAURICE, Designing Mechanical Engineer, General Electric Co., Pittsfield, Mass.

ADAMS, MERLE J., Inspector of Automatic Substations, Cleveland Railway Co., Cleveland, Ohio.

ALCUS, LEWIS SCHERCK, Experimental Tester, Century Electric Co., 1827 Pine St., St. Louis, Mo.

ALLAN, JOHN, c/o A. L. McDonough, Rose St., Plainfield, N. J.

*ANDERSON, ARVID ENGLEBERT, Designing Engineer, Switchboard Dept., General Electric Co., Schenectady, N. Y.

ANDERSON, ARVID E., Electrical Mechanic, Potomac Electric Power Co., Washington; res., Cleveland Park, D. C.

*ANDERSON, EDWARD S., Engineer, Electrical Construction, Minn. & Ontario Paper Co., International Falls, Minn.

ANDERSON, JOHN L., Instructor, Applied Electricity, Tuskegee Institute, Tuskegee, Ala.

ANDERTON, ROBERT HYDE, Asst. Examiner Division 26, U. S. Patent Office, Washington, D. C.

ANTHONY, WILLIAM TIMMS, General Traffic Engineer, Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.

BAGWELL, OMAR C., Transmission & Protection Engineer, The Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.

BANTHIN, JOHN FREDERICK, Inspector, Motor Division, General Electric Co., Bridgeport, Conn.

BARRY, WILLIAM G., General Commercial Supt., The Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.

*BECK, HERBERT H., Student, University of Wisconsin, Madison; res., Fond du Lac, Wis.

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WILSON, ALLAN, Electrical Mechanic, Potomac Electric Power Co., Washington, D. C.
WILSON, CARROLL LOUIS, Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.
WILSON, GERARD, Student, Stanford University, Stanford University, Calif.
WINGO, A. C., Mechanical Electrical Draftsman, Bureau of Power & Light, 207 S. Broadway, Los Angeles, Calif.
WINSCH, EDWIN G., Telephone Engineering Dept., Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.
WITHERELL, HARRISON CUSHMAN, Electrical Contractor, 192 Bedford St., Abington, Mass.
*WITT, TRUMAN ELBERT, Sales Engineer, Century Electric Co., 1827 Pine St., St. Louis, Mo.
WOODRUFF, WALTER W., Electrical Mechanic, Potomac Electric Power Co., 14th & C Sts., N. W., Washington, D. C.; res., Clarendon, Va.
*WORTHLEY, CHARLES BOND, Electrical Engineer, City Light Dept., Tacoma, Wash.
WRAY, FRED LEAHR, Member of Firm Willey-Wray Electric Co., 118 W. 3rd St., Cincinnati, Ohio.
WRIGHT, RATCLIFFE, Distribution Engineer, Buenos Aires Western Railway, Ltd., Calle Bolivia 180, Flores F. C. O., Buenos Aires, S. A.
WRIGHT, WILLIAM HIRAM, Wireman, Potomac Electric Power Co., 14th & C Sts., N. W., Washington, D. C.

Total 272
*Formerly Enrolled Students.

ASSOCIATES REELECTED MARCH 16, 1923

CLARK, JAY ROWLEY, Electrical Contractor, 579 Wellington Ave., Rochester, N. Y.

DRAKE, RALPH E., Telephone Engineer, Western Electric Co., 463 West St., New York, N. Y.

FARMER, FRANK HARVEY, Erecting Engineer, Canadian Westinghouse Company, Hamilton; res., Chippewa, Ont., Can.

MORRILL, EDWARD FRANCIS, Equipment Engineer, The Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.

PONSONBY, AMOS ALBERT, Engineering Dept., Hudson Coal Co., Pine-Ridge Mines, Parsons; for mail, Miners Mills, Pa.

SHIPEK, ADOLPH, Asst. Draftsman, City Engineer's Office, Skagit Development, Seattle, Wash.

MEMBERS ELECTED MARCH 16, 1923

BALTZLY, CLIFFORD C., Supt., Station Economy, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

BOOTH, WILLIAM THOMAS, In Charge of Machine Switching Apparatus Design, Western Electric Co., 463 West St., New York; res., Flushing, N. Y.

BROWN, ERNEST FURMAN, Appraisal Engineer, Southern Bell Tel. & Tel. Co., 78 S. Pryor St., Atlanta, Ga.

COUSINS, ROBERT E., Field Engineer, Westinghouse Elec. & Mfg. Co., 467-10th Ave., New York, N. Y.

DUNBAR, ROBERT V., Manager, Equipment Sales & Engineering Co., 50 Church St., New York, N. Y.

FERGUSON, SAMUEL, Managing Director, Ferguson Pailin Ltd., Edward St., Higher Openshaw, Manchester, Eng.

KULSKE, ROBERT HERRMAN, Electrical Engineer and Contractor, Windsor House, 113 Long St., Cape Town, South Africa.

MILLER, DANIEL DANEY, In Charge of Electrical & Mechanical Design Group, Western Electric Co.,463 West St.,New York, N. Y.

NEEDHAM, JOHN T., President, Pneumatic Tube Supply Co., 17 Steiner Place, N. Plainfield, N. J.

RYAN, JOHN J., Superintendent, New York Edison Co., 140th St. & Rider Ave.,New York, N. Y.

WILSON, RICHARD HENRY, Electrical Engineer, Western Electric Co., Inc., 463 West St., New York, N. Y.; res., Millburn, N. J.

TRANSFERRED TO GRADE OF FELLOW, MARCH 16, 1923

MILLS, JOHN, Assistant Personnel Manager, Western Electric Co., New York, N. Y.

PECK, EMERSON P., General Supt., Electrical Dept., Utica Gas & Electric Co., Utica, N. Y.

THURSTON, ERNEST B., Chief Electrical Engineer, Haughton Elevator & Machine Co., Toledo, O.

TRACY, ATLEE H., Electrical Engineer, Byllesby Engineering & Management Corp., Chicago, Ill.

TRANSFERRED TO GRADE OF MEMBER, MARCH 16, 1923

BASSETT, JOHN B., Assistant District Engineer, General Electric Co., New York, N. Y.

BEERS, HAROLD S., Electrical Superintendent, Tallassee Power Co., Badin, N. C.

BOWLER, WILLIAM E., District Line Material Manager, Western Electric Co., Atlanta, Ga.

CLARDY, WILL J., Electrical Engineer, General Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

HUMPHREY, GEORGE S., Electrical Engineer, West Penn Power Co., Pittsburgh, Pa.

KAHLER, CHARLES P., Electrical Engineer, Oregon Short Line Railroad (U. P. System) Salt Lake City, Utah.

KELLOGG, CHARLES W., Stone & Webster, Inc., Boston, Mass.

McGREGOR, ANDREW J., Engineer, Ray D. Lillibridge, Inc., New York, N. Y.

PHILPOTT, HENRY E. R., Testing Engineer, Lake Coleridge Hydro-Electric Power Supply, Addington, N. Z.

PRICE, GEORGE F., Assistant Electrical Engineer, Department of Education, City of New York, Brooklyn, N. Y.

QUENTIN, GEORGE W., Sales Engineer, Duquesne Light Co., Pittsburgh, Pa.

WILSON, GEORGE B., Chief Engineer, Service Section, Apparatus Sales Dept., Canadian General Electric Co., Toronto, Ont.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held November 6, 1922, and March 12, 1923, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

RUNYON, FREDERICK O., Senior Partner, Runyon & Carey, Newark, N. J.

To Grade of Member

HAMMATT, CLARENCE S., President, Consolidated Engineering Co., Jacksonville, Fla.

KEELER, HUGH E., Assistant Professor of Mechanical Engineering, University of Michigan, Ann Arbor, Mich.

KRAUSNICK, WALTER, Associate Professor of Electrical Engineering, College of Engineering, Newark Technical School, Newark, N. J.

MERRIAM, EZRA B., Executive Engineer, Switchboard Dept., General Electric Co., Schenectady, N. Y.

READ, WILLIAM G., Engineer-Accountant, Public Utilities Commission, State of Kansas, Topeka, Kans.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before April 30, 1922.

Abey, Harry Raymond, Philadelphia, Pa.
Alford, Reuel S., Phoenixville, Pa.
Allen, Charles F., New York, N. Y.
Anderson, Arthur N., (Fellow), Bridgeville, Pa.
Anderson, Harold W., Lawrence, Kansas.
Anderson, William A., Quincy, Mass.
Bailey, James C., Chicago, Ill.
Baldwin, John R., Bridgeport, Conn.
Bamber, William R., New York, N. Y.
Barclay, J. Roy, Chicago, Ill.
Barrow, Frederick A., Louisburg, C. B.
Bascome, George L., (Member), Scranton, Pa.
Best, Fred H., (Member), New York, N. Y.
Bishop, James W., Detroit, Mich.
Bohn, Donald I., Schenectady, N. Y.
Boozier, Charles C., E. Pittsburgh, Pa.
Bower, Wilfred H., Los Angeles, Calif.
Bowman, Francis H., (Member), W. Lynn, Mass.
Boyle, William E., (Member), New York, N. Y.
Breisch, Edgar W., E. Pittsburgh, Pa.
Brinton, Howard T., Yonkers, N. Y.
Brokaw, George A., Mt. Vernon, N. Y.
Brown, Campbell A., Pittsburgh, Pa.
Buchman, Henry F., (Member), Ampere, N. J.
Burton, Everett T., New York, N. Y.
Bushfield, Charles H., Newark, Ohio.
Callahan, Vincent T., Bridgeport, Conn.
Callahan, William F., New York, N. Y.
Cameron, Stanley M., Washington, D. C.
Campbell, Frank W., Cleveland, Ohio
Campbell, Richard D., Washington, D. C.
Card, Thomas B., Dayton, Ohio.
Chapman, Fred I., Boston, Mass.
Champreux, Alfred J., San Francisco, Calif.
Clark, William A., New York, N. Y.
Clayton, Arthur E., New York, N. Y.
Conover, Albert W., Richmond, Va.
Cooke, Bennett W., (Member), Chicago, Ill.
Coover, William E., Brooklyn, N. Y.
Cornell, Oliver K., Middleport, N. Y.
Cornford, Fred J., Wheeling, W. Va.
Crawford, Thomas G., Pittsfield, Mass.
Cummings, Thomas, Newburgh, N. Y.
Cunha, Stanley H., Montreal, Quebec.
Daline, Oscar L., Portland, Ore.
Davidson, Ray V., Detroit, Mich.
de Goede, Arian H., Schenectady, N. Y.
Delaney, James P., Los Angeles, Calif.
Day, Thomas H., Hartford, Conn.
Demonet, Eugene A., Jr., New York, N. Y.
Dickinson, Ernest, Kimberley, B. C.
Dickson, Thomas H., Pictou, N. S.
Dobbs, Oscar, Nowata, Okla.
Donelson, Leroy E., Sacramento, Calif.
Doran, James P., Montreal, P. Q.
Duncanson, Walter W., Los Angeles, Calif.
Eernisse, James G., Tacoma, Wash.
Erben, Henry V., Schenectady, N. Y.
Fairgrieve, Robert P., Boston, Mass.
Farrar, Carlos A., Los Angeles, Calif.
Fitzgerald, Robert L., Ft. Wayne, Ind.
Flannery, Neil G., Halifax, N. S.
Fogler, Florence, Schenectady, N. Y.
Folan, Harrison G., (Member), Brooklyn, N. Y.
Foland, Harry S., New York, N. Y.
Fraser, Robert A., Boston, Mass.
Frasher, George, Brooklyn, N. Y.
Frederick, W. H., Jackson, Mich.
Freed, Irvin, Baltimore, Md.
Freezee, Walter D., Detroit, Mich.
Frisbee, Joseph E., Portsmouth, N. H.
Frost, William S. M., Lynchburg, Va.
Garagan, Stephen J., Schenectady, N. Y.
Gerold, Frank G. M., New York, N. Y.
Gibson, Leonard O., Rawlins, Wyoming.
Gordon, Walter R., Boston, Mass.
Gough, William J., Brooklyn, N. Y.
Gould, William I., Allentown, Pa.
Gowan, Arthur J., Lynn, Mass.
Grajales, Fernando L., Mexico, Mex.
Graves, Herbert C., Cincinnati, O.
Green, Estill I., New York, N. Y.
Greenway, Fred N., Detroit, Mich.
Gruninger, Andrew F., Newark, N. J.
Hadley, Thomas R., (Member), New York, N. Y.
Hahn, Herbert J., Newark, N. J.
Hanson, J. Willis M., Philadelphia, Pa.
Harris, Alexander W., St. Louis, Mo.
Hart, C. D., Chicago, Ill.
Hartmann, Richard W., Philadelphia, Pa.
Heath, Leslie O., (Member), Philadelphia, Pa.
Hennequin, J. H., Cincinnati, Ohio.
Henrici, Hermann C., (Member), Kansas City, Mo.
Henrickson, William S., Worcester, Mass.
Henritze, Thomas L., Pikeville, Ky.
Herbig, Henry F., New York, N. Y.
Holdcraft, John M., Cleveland, Ohio.
Hopfen, Bernard, New York, N. Y.
Hoschke, William B., Allentown, Pa.
Huber, Harold L., (Member), Washington, D. C.
Hussey, Richard B., W. Lynn, Mass.
Hutchins, Charles C., E. Pittsburgh, Pa.
Hyneman, John R., New York, N. Y.
Ingberg, John E., Scotia, N. Y.
Ingels, Clarence W., Washington, D. C.
Jackson, George A., Waltham, Mass.
Janssen, George, Centralia, Ill.
Johansen, Johannes, Oakland, Calif.
Jones, J. Randolph, Toronto, Ont.
Kassenbrock, Christopher A., Brooklyn, N. Y.
Katz, Abraham, Boston, Mass.
Keith, John T., Sturgeon Falls, Ont.
Kennedy, Clifton D., Chicago, Ill.
Ketross, James R., Pittsburgh, Pa.
Lane, Francis H., (Fellow), Chicago, Ill.
Lane, Raymond A., E. Pittsburgh, Pa.
Lee, Victor L., Everett, Mass.
Leibfried, William, (Member), Long Island City, N. Y.
Levison, Emanuel, (Member), Cleveland, Ohio.

Lewis, Newton A., Pittsfield, Mass.
Little, George F., New York, N. Y.
Little, William P., (Member), Kingston, Pa.
Littleton, Jesse T., Jr., Corning, N. Y.
Lormann, Robert, Cleveland, Ohio.
Maher, George, Boston, Mass.
Mallory, Roy, Cleveland, Ohio.
Manz, Merrell Wiley, Barberton, Ohio.
Mastick, Reuben W., San Francisco, Calif.
Masury, Alfred F., (Fellow), New York, N. Y.
McCrea, Hugh A., Schenectady, N. Y.
McDougall, Daniel J., Denver, Colo.
McKinstry, Samuel, Bridgeport, Conn.
Merwin, Elwood A., Bridgeport, Conn.
Mills, George E., Toronto, Ont.
Mills, Harry O., E. Pittsburgh, Pa.
Molyneaux, Henry A., Syracuse, N. Y.
Moore, David A., Springfield, Mass.
Morisuye, Masa M., Ithaca, N. Y.
Moscrip, Robert, Indianapolis, Ind.
Murdock, Paul S., Ampere, N. J.
Murozumi, Kumazo, Ithaca, N. Y.
Murray, George H., Norwich, Conn.
Naeter, Albrecht, Ithaca, N. Y.
Nawn, John A., Boston, Mass.
Needham, Robert J., (Member), Montreal, Que.
Nelles, Roy, New York, N. Y.
Newhall, Ralph P., Lynn, Mass.
Noack, Harry R., San Francisco, Calif.
Norberg, Clifford M., Cleveland, Ohio.
Nulsen, William B., Schenectady, N. Y.
Okey, Perry, Columbus, Ohio.
Ormerod, Harold F., Yonkers, N. Y.
Overbeck, Hermann G., Denver, Colo.
Parker, Frank H., New York, N. Y.
Paulson, Carl G., Boston, Mass.
Pearson, Ernest, Columbus, Ohio.
Peckham, John J., Cleveland, Ohio.
Penny, Henry B., Nelson, B. C.
Peterson, Andrew, New York, N. Y.
Petit, Francis W., E. Pittsburgh, Pa.
Phelps, Boyd, Hartford, Conn.
Pinckard, Frank E., Cincinnati, Ohio.
Pohnan, Frank J., Chicago, Ill.
Priest, Lucian C., Charlestown, Mass.
Pulham, Wilfred W., Denver, Colo.
Punshon, Oliver H. G., Oakland, Calif.
Purdy, Harry E., Jr., Yonkers, N. Y.
Pursell, Leighton C., Allentown, Pa.
Ralston, Fred W., Lynn, Mass.
Redmon, Roy S., Cincinnati, Ohio.
Reilly, William F., New York, N. Y.
Rhodes, Harold A., New York, N. Y.
Rice, Burleigh L., Chino, Calif.
Ritter, Edward L., San Francisco, Calif.
Robeson, C. E., Cleveland, Ohio.
Robinson, Lyle B., Pittsfield, Mass.
Roy, J. Ernest, Newton, Mass.
Runyon, J. C., Port Monmouth, N. J.
Rystedt, Suen E., Schenectady, N. Y.
Saltmarsh, William, St. Louis, Mo.
Sandeson, Stephen E., Denver, Colo.
Shiffett Bert R., Emmetsburg, Iowa
Schmidt, Alwin, Boston, Mass.
Scholl, Chester C., Chicago, Ill.
Schultz, Byron W., Chicago, Ill.
Schwennicke, Otto A., Los Angeles, Calif.
Sherman, Maurice, Bloomfield, N. J.
Sill, Harold D., Power, W. Va.
Skretting, Almer, Milwaukee, Wis.
Small, Fred F., (Member), Los Angeles, Calif.
Smythe, James D., New York, N. Y.
Snyder, S. Q., Brooklyn, N. Y.
Soper, Robert H., Central Cespedes, Camaguey, Cuba
Soule, Clayton E., Drumright, Okla.
Spencer, Rhodes V., Seattle, Wash.
Sprung, Abraham, Brooklyn, N. Y.
Steinau, John M., New Rochelle, N. Y.
Summerville, Alan O., Jamaica Plain, Mass.
Sutherland, Robert G., Pinar del Rio, Cuba
Tepel, Herman A., Cleveland, Ohio.
Terry, Gerard W., New Haven, Conn.
Tripp, William A., Lynn, Mass.
Turner, Charles C., Pittsfield, Mass.
Veit, William A., Jr., New York, N. Y.
Voelcker, John W., Cambridge, Mass.
Vogelman, Jack, Oakland, Calif.
Volland, Roland A., St. Louis, Mo.
Wagner, Harry E., Portland, Ore.
Wallof, Arthur L., Minneapolis, Minn.
Walsh, John R., Brooklyn, N. Y.
Warren, Arthur J., Chicago, Ill.
Watrous, Royal E., Uncasville, Conn.
Watson, Frank C., (Member), Huntington, W. Va.
Watson, Howard E., Brooklyn, N. Y.
Weatherspoon, Edward H., (Member), New York, N. Y.
Werner, John F., Brooklyn, N. Y.
Wheeler, Bailey D., New York, N. Y.
White, William C., Schenectady, N. Y.
Whitely, Fred, Fon du Lac, Wis.
Willby, Norman H., E. Pittsburgh, Pa.
Wille, Henry E., Seattle, Wash.
Wilsey, Fay T., Cleveland, Ohio.
Williams, Charles K., Cleveland, Ohio
Williamson, Anderson R., Essington, Pa.
Wilson, Bennett D., Middlesboro, Ky.
Wilson, William, (Member), New York, N. Y.
Wolford, James E., Wheeling, W. Va.
Yates, Clarence C., College Station, Texas.
Yost, Daniel M., Edmonds, Wash.
Zant, Lawrence N., Seattle, Wash.

Total 230.

Foreign

Bellows, Guy, (Member), Sao Paulo, Brazil, S. A.
Davoust, Albert, Paris, France.
Gupta, Birendra C., (Fellow), Cambridge, Mass.
Imasato, Kenichi, Sukegawa, Ibaraki-ken, Japan.
Kato, Takeo, Kobe, Japan.
Singer, Maurice W., Loughborough, Leicester, Eng.
Stephens, Lionel C., Christchurch, N. Z.
Uchimaru, Yasuji, Kobe, Japan.
Waddicor, Harold, Manchester, Eng.
Wheeler, Willoughby S., Wolverhampton, Eng.
Wilson, John E., Shanghai, China.

Total 11.

STUDENTS ENROLLED MARCH 16, 1923

16819 Patisteas, Michael J., Mass. Inst. of Tech.
16820 Warn, Richard E., Rice Institute
16821 Fraser, William A., Northeastern Univ.
16822 Fisher, Merle L., Carnegie Inst. of Tech.
16823 Hughes, E. Temple, Penn. State College
16824 Lippitt, Harry, Brooklyn Polytechnic Inst.
16825 Potts, J. Arlington, University of Wisconsin
16826 Whittington, John W., Mass. Inst. of Tech.
16827 Hughes, Albert A., University of Missouri
16828 Shaw, Ronald H., Mass. Inst. of Tech.
16829 Johnson, Raymond, Mass. Inst. of Tech.
16830 Orr, Allen A., Jr., Drexel Institute
16831 Stover, Peter A., University of Iowa
16832 Bean, George E., University of Wisconsin
16833 Frantz, Jesse D., Oregon Agr. College
16834 Walbridge, Frank E., Kansas State Agr. College
16835 Mansfield, T. E., University of Texas
16836 Rabke, Raymond F., University of Texas
16837 Smith, Wilton Merle, Penn. State College
16838 Fry, Lloyd C., Bucknell University
16839 Harris, Hiram D., Rensselaer Poly. Inst.
16840 Rouse, Andrew F., Rensselaer Poly. Inst.
16841 Bender, David S., Rensselaer Poly. Inst.
16842 Sleeper, Floyd E., University of Vermont
16843 Rissberger, John M., Oregon Agri. College
16844 Skells, George W., Oregon Agri. College
16845 Lentz, B. F., Oregon Agricultural Coll.
16846 Smith, Wayne W., Oklahoma A. & M. Coll.
16847 Knight, Robert H., Northeastern Univ.
16848 Griffin, William F., Clemson College
16849 Bischoff, Charles F., Columbia University
16850 Kaufman, Theodore, Columbia University
16851 Jenks, Donald G., Northeastern University
16852 Vines, Frederick D. L., Northeastern Univ.
16853 Baker, Charles M., School of Engg. of Mil.
16854 Brown, N. H., School of Engg. of Mil.
16855 Evans, W. Seymour, School of Engineering of Milwaukee
16856 Gensch, Frederick W. A., School of Engineering of Milwaukee
16857 Hannan, Harold S., School of Engg. of Mil.
16858 Hansen, Walter E., School of Engg. of Mil.
16859 Herbst, Charles H., Jr., School of Engineering of Milwaukee
16860 Hoedemaker, Peter, School of Engg. of Mil.
16861 Lithgow, Ellis D., School of Engg. of Mil.
16862 Lund, Harold S., School of Engg. of Mil.
16863 McCartney, Curtice B., School of Engineering of Milwaukee
16864 McVay, Wilbur J., School of Engg. of Mil.
16865 Mellen, Elwood R., School of Engg. of Mil.
16866 Miller, Ridley, School of Engg. of Mil.
16867 Hoch, Laurence E., School of Engg. of Mil.
16868 Schrotberger, Clyde H., School of Engineering of Milwaukee
16869 Talbott, John A., School of Engg. of Mil.
16870 Underwood, Thomas H., School of Engineering of Milwaukee
16871 Hird, Allen B., Iowa State College
16872 Leaphart, F. P. Jr., Georgia School of Tech.
16873 Henderson, Malcolm V., Iowa State Coll.
16874 Marcroft, Harold C., Univ. of Minnesota
16875 Harmon, Glenn R., Iowa State College
16876 Diment, J. Morton, Univ. of Minnesota
16877 Renzi, Stephen E., Cooper Union
16878 Harte, Joseph A., Cooper Union
16879 Dean, Donald M., Cooper Union
16880 Trachtman, Harry, Cooper Union
16881 Masters, Albert G., University of Michigan
16882 Webster, Leslie, University of Michigan
16883 Jarvis, Kenneth W., Ohio State University
16884 Mundwiler, Charles E., Ohio State Univ.
16885 Dickinson, John F., Ohio State University
16886 Duncan, William T., Ohio State Univ.
16887 Fies, John, Ohio State University
16888 Forbes, Lester N., Ohio State University
16889 Gardner, Emmet G., Ohio State University
16890 Thomas, J. Wayne, Ohio State University
16891 Sutcliffe, Raymond S., Rhode Island State College
16892 Simmons, Allan B., Clarkson Coll. of Tech.
16893 Puls, Edwin E., University of Illinois
16894 Marquardt, John W., Univ. of Illinois
16895 Anderson, Roy E., Oregon Agri. Coll.
16896 Wells, Robert L. G., University of Idaho
16897 Secord, Harold W. M., Northeastern Univ.
16898 Strittmatter, Oliver R., Penn. State Coll.
16899 Farabaugh, Cletus F., Penn. State Coll.
16900 Scheering, Walter S., Univ. of Cincinnati
16901 Groh, George H., Penn. State College
16902 Hoyt, Royal S., Clarkson Coll. of Tech.
16903 Loubris, Gaston E., Northeastern Univ.
16904 Bushby, Merritt, University of Iowa
16905 Greathead, J. McCarrell D., Penn. State College
16906 Arlt, Herbert G., Stevens Inst of Tech.
16907 Caldwell, Sidney E., Oregon Agri. College
16908 Van Ackere, George H., Oregon Agri. Coll.
16909 Meiter, Carl A., Carnegie Inst. of Tech.
16910 Best, Charles A., Oregon Agri. College
16911 Strong, L. L., Oregon Agricultural Coll.
16912 Munhall, Walter F., Penn. State College
16913 Harnett, Daniel E., Columbia University
16914 Mandley, Wilfred J., Oregon Agri. Coll.
16915 Haynes, Ralph F., Oregon Agri. Coll.
16916 Yadon, Charles M., Oregon Agri. Coll.
16917 Holtgren, Clifford C., Oregon Agri. Coll.
16918 Eaden, Neal, State Coll. of Washington
16919 Loukianoff, Gregory M., Mass. Inst. of Tech.
16920 Williams, George F. H., Clarkson Coll. of Technology
16921 Cummings, William M., North Carolina State College
16922 Hamrick, Howard D., North Carolina State College
16923 Robertson, Everard P., Univ. of Illinois
16924 Brown, Franklin M., Case School of Applied Science
16925 Gale, Ralph E., Univ. of Washington
16926 Brackett, Leroy W., University of Wash.
16927 Heinz, Winfield B., Univ. of Washington
16928 Kirshen, Simon, Mass. Inst. of Tech.
16929 Wray, James G., Univ. of Arizona
16930 Moyle, Edward, University of Arizona
16931 Scarlott, Charles A., Univ. of Arizona
16932 Grasmoen, William J., Univ. of Arizona
16933 Draper, Thomas, University of Arizona

16934 Owens, John H., University of Arizona
16935 Barton, Stanley B., Univ. of California
16936 Berdlis, Steve L., Univ. of California
16937 Brand, George S., Univ. of California
16938 Bruere, William B., Univ. of California
16939 Enloe, Ralph T., Univ. of California
16940 Enns, Waldo E., Univ. of California
16941 Hatfield, Robert M., Univ. of California
16942 Hiller, John G., Univ. of California
16943 Jacobs, Eastman N., Univ. of California
16944 Johnson, Frank L., Univ. of California
16945 Lincoln, Charles E., Univ. of California
16946 Maeshner, Edward A., Univ. of California
16947 Romander, C. H., Univ. of California
16948 Shepherd, William R., Univ. of California
16949 Smith, Ward B., Univ. of California
16950 Stinchfield, J. Maxwell, Univ. of Calif.
16951 Wenzel, Arthur E., Univ. of California
16952 Hayward, Sheldon C., Ohio State Univ.
16953 Monteith, Alexander C., Queens Univ.
16954 Lange, Herbert L., Montana State Coll.
16955 Branovan, Leo, University of Wisconsin
16956 Everett, Harry S., Bucknell University
16957 Caradonna, Victor, Jr., Worcester Polytechnic Institute
16958 Carr, William J., Alabama Poly. Inst.
16959 Levy, Edward J., Alabama Poly. Inst.
16960 Bates, John W., Alabama Poly. Inst.
16961 Tucker, Arthur H., Alabama Poly. Inst.
16962 Jones, Ruel C., Penn. State College
16963 Winston, John McC., Rice Institute
16964 McDonald, R. V., Alabama Poly. Inst.
16965 Mosley, William K., Alabama Poly. Inst.
16966 Kuehlthau, Wareham A., Univ. of Wis.
16967 Rogers, Louis B., Rice Institute
16968 Chauls, Reuben, Stevens Inst. of Tech.
16969 Gegg, Joseph H., Penn. State College
16970 Shore, Henry, Mass. Inst. of Tech.
16971 Anderson, Albert S., Mass. Inst. of Tech.
16972 Hance, Paul D., Univ. of Illinois
16973 Fischer, Herbert B., Univ. of Wisconsin
16974 Fowler, Earl W., Northeastern University
16975 Prudhomme, Donald J., Oregon Agri. Coll.
16976 Tubbs, Harold B., Oregon Agri. Coll.
16977 Weir, John M., University of Washington
16978 Clark, Stanley A., Univ. of Washington
16979 Szabo, Alexander, Rutgers College
Total 161.

OFFICERS OF A. I. E. E. 1922-1923

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Frank B. Jewett

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William McClellan

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C. G. Adsit
F. W. Springer
Robert Sibley
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G. Faccioli
W. I. Slichter
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H. W. Eales
H. T. Plumb

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H. M. Hobart
Ernest Lunn
G. L. Knight

Treasurer
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Secretary
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Honorary Secretary
Ralph W. Pope

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Carroll M. Mauseau, Caixa Postal No. 571 Rio de Janeiro, Brazil.
Charles le Maistre, 28 Victoria St., London, S. W., England.
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E., France.
H. P. Gibbs, Tata Sons, Ltd., Navsari Building, Fort Bombay, India.
Guido Semenza, N. 10 Via S. Radegonda, Milan, Italy.
Lawrence Birks, Public Works Department, Wellington, New Zealand.
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(A list of the personnel of Institute committees may be found in the January issue of the Journal. Will be reprinted in the June Journal.)

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(The Institute is represented on the following bodies; the names of the representatives may be found in the January issue of the Journal and wil be published again in the June issue.)

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Total 70		

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Traffic Control Devices.—Booklet, 8 pp. entitled "Traficons," describing devices employed in a new system of traffic control. Line Material Company, So. Milwaukee, Wis.

Linemen's Tools.—Bulletin 2, 8 pp. "Hot Line Tools." Describes tools for replacing insulators and for effecting other repairs on live lines. W. T. Safety Tool Company, Decatur, Ill.

Multi-Speed Motors.—Bulletin, 12 pp. Describes the Watson multi-speed motor, squirrel-cage type and pictures applications in a number of industries. The Louis Allis Company, Milwaukee, Wis.

Single-Phase Motors.—Bulletin 131, 16 pp. Contains instructions for ordering and adjusting repair parts of single-phase repulsion induction motors. Wagner Electric Corporation, St. Louis, Mo.

Battery Charging Equipment.—Bulletin, 12 pp. Describes alternating-current battery charging equipment for industrial trucks and tractors. The Acme Electric & Manufacturing Company, Cleveland, Ohio.

Electric Furnace. Bulletin 2, 8 pp. Describes the Ajax-Northrup high-frequency induction furnace, 15 kv-a. converter and small furnaces for temperatures up to 2000 deg. cent. Ajax Electrothermic Corporation, Trenton, N. J.

Steam Power Plants.—Booklet, 16 pp. "Steam Power" is the title of a booklet now being distributed by the J. G. White Engineering Corporation, 43 Exchange Place, New York. The book is illustrative and descriptive of some of the more important steam power plants which have been built by this corporation.

Centrifugal Pumps.—Bulletin 1632-F, 58 pp. Describes numerous industrial applications of centrifugal pumps and pumping units, and contains results of tests, tables and curves. The construction of each type of pump is pictured in detail, and instructions relative to installation and operation are also given. Allis-Chalmers Manufacturing Co., Milwaukee, Wis.

Trademarks.—Booklet, 48 pp. Outlines the salient features of trademark law and discusses the subject of unfair competition. Patents—Booklet, 56 pp. Prepared to serve as a convenient handbook, presenting in concise form for ready reference the leading points of domestic and foreign law and practise relative to patents and patent practise. Richards & Geier, 277 Broadway, New York.

Portable Timing Device.—Bulletin 46053, 4 pp. A device consisting of an encased clock, to be used with a standardized clock as a means of secondary timing, to supplant the stop watch. Accuracy of 0.1 in 60 seconds is attained with this device, which may be used with graphic instruments, measurements of angular velocities, and for indicating a definite time interval ranging from one second to any whole number of minutes. General Electric Company, Schenectady, N. Y.

Synchronous Motor Drive for Ammonia Compressors.—Bulletin 41316, 12 pp. Describes the development of ice making machines and a line of 50 degree motors for the low speed operation of two-cylinder double acting ammonia compressors. The bulletin presents a method of analysis for conversion of a distilled water ice plant to an electrically driven "raw water plant." General Electric Company, Schenectady, N. Y.

Powdered Coal Tests.—Serial No. 2438 entitled "Tests of Large Boiler Fired With Powdered Coal" by Henry Kreisinger, Research Engineer, Combustion Engineering Corporation, New York and John Blizard, Fuel Engineer, U. S. Bureau of Mines, presents some of the results of tests carried out at the Lakeside Station of the Milwaukee Electric Railway and Light Company by the fuel section of the Bureau of Mines, in connection with the Research Department of the Combustion Engineering Corporation. The preliminary statement may be obtained from the Bureau of Mines, Washington, D. C., or from the Combustion Engineering Corporation, Broad Street, New York. The full report of the tests will be published later by the Bureau of Mines.

NOTES OF THE INDUSTRY

Pure Carbon Company, Wellsville, N. Y.—Announcement is made of the recent appointment of an Alabama representative, the Commercial Electric Sales Company, 1322 Empire Building, Birmingham, Ala.

Killark Electric Manufacturing Company, St. Louis, Mo.—The Electric Sales Company, 111 New Montgomery Street, San Francisco, has been appointed sales agent for northern California of the Killark line of conduit fittings, bell ringing transformers, enclosed fuses, etc.

The Sterling Varnish Company, Pittsburgh, Pa.—Announcement is made that B. D. Smith, who until February 1st was with the Engineering Department of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, has accepted the position of eastern manager, and after April 1st will take up his duties at the company's Eastern office, Arlington, N. J.

Gibb Instrument Company, Bay City, Mich., manufacturer of electric welding equipment, has opened a sales office in the General Motors Building, Detroit, in charge of F. M. Luchs formerly chief engineer for the company.

A new sales office has also been opened at Cleveland, Ohio, 2104 East Superior Avenue, in charge of W. O. Little.

Standard Underground Cable Company.—The general offices and Pittsburgh sales office of the Company have been moved from the Westinghouse Building, where they have been located for many years, to the new factory and office building at 100-108 Seventeenth Street. The new building is a four-story steel and brick structure just completed, occupying the entire block between Sixteenth and Seventeenth Streets. This block was the site of the Company's first factory erected in 1883.

A branch of the Company's St. Louis office has been opened in the Scarritt Arcade Building, 817 Walnut Street, Kansas City, Mo. E. H. Shutt, who has been with the company for several years, will be in charge as district sales agent.

Westinghouse Electric & Manufacturing Company, East Pittsburgh.—The United Railways & Electric Company of Baltimore has placed a contract amounting to approximately $425,000 for the erection of four automatic substations in the downtown section of the city of Baltimore. This will be one of the largest automatic substation installations in the country. The contract calls for four 3000-kw. automatic substations, each of which consist of two 1500-kw. 25-cycle, shunt-wound, synchronous converters with single-phase, 13,200-volt transformers, and automatic switching equipment.

The Westinghouse Company has just completed for the Southern California Edison company six very large single-phase auto-transformers. They are of the water-cooled type, designed for outdoor service in the Eagle Rock substation of the company, to form a part of the 220,000-volt power system. Each unit is rated at 36,700 kv-a., 50 cycles, giving a bank capacity of over 100,000 kv-a. An idea of the size of each transformer will be realized by the following figures: The tank, which has flat sides and half round ends, is 10 feet 3 inches wide and 14 feet 3 inches long. It is approximately 15 feet high, and in order that it may be shipped the side walls are divided near the middle so that the top portion can be lifted off. The height from the ground to the tip of the condenser bushings is about 27 feet. Five tons of copper and about twenty-two tons of iron laminations were required for each transformer. The total weight of each complete transformer is over 90 tons, and the oil capacity more than 9000 gallons.